THE UTILITY OF

SULPHATE OF AMMONIA

IN

AGRICULTURE.

By

JAMES MUIR, M.R.A.C.

Price One Shilling.

THE PRIZE ESSAY ON SULPHATE OF AMMONIA.

THE UTILITY OF SULPHATE OF AMMONIA IN AGRICULTURE.

BY

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CONTENTS.

THE

UTILITY OF SULPHATE OF AMMONIA

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AGRICULTURE.

More than half a century ago, in dealing with the subject of the "Food of Plants," Fownes wrote as follows: "I beg once more to call attention to the salts of ammonia. Should these really be found to produce the beneficial effects anticipated, we shall possess at home, within the limits of our own island, resources for the improvement of agriculture compared with which guano, and nitrate of soda, and all such things, are quite insignificant—resources which only require to be judiciously used to produce the most extraordinary results."*

This prediction was made when the value of nitrogenous manures was very little understood, and when artificial top-dressings in particular were undergoing their first trials, and were regarded with great suspicion by the majority of agriculturists. Subsequent discovery and research have proved the general correctness of the forecast, though the judicious use of salts of ammonia is not met with as often as might be. It is the object of this essay to point out the manner of action of sulphate of ammonia; and, relying only on results of actual experiments, to show how it may best be used on the various crops of the farm with a view to profit.

Manufacture of Sulphate of Ammonia.

Sulphate of ammonia, in common with other compounds of ammonia, is obtained chiefly as a bye-product in the manufacture of coal gas. When coal is heated in the retorts to drive off the gas, most of the nitrogen it contains combines with hydrogen, also found in the coal, to form ammonia—a gas consisting of fourteen parts by weight of nitrogen, and three parts of hydrogen. To remove this ammonia from the coal gas, in which it would be a harmful ingredient, the mixture is usually brought into contact with water in a special apparatus called a "scrubber," when the ammonia is dissolved, while the rest of the gas passes on.

* "Journal of the Royal Agricultural Society of England," Vol. IV.

Steam is blown through this solution of ammonia and condensed in sulphuric acid, when the compound sulphate of ammonia is formed by combination between the ammonia and the acid.

In a similar manner, sulphate of ammonia is obtained from coke-ovens, blast-furnaces, shale-oil works, and to a slight extent in the manufacture of charcoal from bones. In France, a certain amount is derived from the ammoniacal liquids from cesspools. Proposals have also been put forward for producing sulphate of ammonia by the heating and destructive distillation of wool refuse and other animal matter containing nitrogen, and from peat; but these methods are not yet of practical importance.

The production of sulphate of ammonia in this country has steadily increased for a number of years; the output having risen from about 75,000 tons in 1883 to 151,500 tons in 1893, and 196,000 tons per annum at the present time. The amount produced in the whole of Europe at present is estimated by Sir William Crookes* at about 400,000 tons per annum.

Sulphate of ammonia belongs to the class of *Nitrogenous Manures—i.e.*, those which are valuable for the nitrogen they contain. We must, therefore, consider it as a source of nitrogen only; bearing in mind that if crops require other substances, they must be supplied from other sources. We will, therefore, first deal with the plant's requirements as to nitrogen, and the effect of nitrogenous manurings generally.

Substances Essential for Plant Growth.

There are in all ten substances which are absolutely essential for plant growth—that is, if any one of them is deficient or absent from the soil, the crop grown will be deficient or will fail accordingly. Many other substances are usually taken up by plants; but these can be dispensed with. Of the essential elements, the majority are supplied naturally in ample quantity—carbon chiefly by the carbon dioxide (carbonic acid) in the air, hydrogen and oxygen in water, lime, magnesia, iron, and sulphur as constituents of the soil; though, as we shall see, the quantity of lime may be deficient. We find, therefore, that the substances that the farmer must supply to his crops are usually only the three—nitrogen, phosphates, and potash; and even of these, potash is sometimes not required, as it often occurs in large quantities in the soil.

Natural Supplies of Nitrogen to the Plant.

Of all the essential constituents, nitrogen is most likely to be lacking in any state in which it can be used by plants. There is, of course, an unlimited quantity of free nitrogen in the air; but in that state it is useless, for plants can only

* British Association Presidential Address, 1898.

take it up when it is fixed or combined with oxygen or some other element. Combined nitrogen is supplied naturally in rain-water, and in dew and hoar-frost; but the total average quantity so added to the soil was estimated at Rothamsted* to be only about 4½ lbs. per acre per annum—a good deal less than is required by any ordinary farm crop.

Clover, beans, and other leguminous plants make the soil on which they grow richer in combined nitrogen. It was first shown by Hellriegel and Wilfarth that this family of plants normally have on their roots small nodules, containing bacteria which have the important power of using the free nitrogen of the air, and preparing it for the use of their hosts. The amount of nitrogen thus obtained, and left in the soil as root and leaf residue, is often very large. These facts must be remembered when we come to deal with the effects of nitrogenous manures on leguminous crops.

Losses of Nitrogen from the Soil.

Whatever the quantity of nitrogen in the soil it is always liable to loss, apart from its removal by crops. Nitrogen in the soil may be said to be always in one of three forms—viz.

1.—Nitrogenous organic matter.
2.—Ammonia.
3.—Nitrates.

In the first form, as organic matter—*i.e.*, the remains of plant or animal life—the nitrogen is for the most part safe from loss. Sooner or later, however, it is liable to be acted upon by bacteria in the soil, and changed into the second form, when in the majority of soils it is still retained; clay and humus being able to hold or "fix" ammonia, while sand, gravel, and lime have no *absorptive power*, as it is called. Eventually organic and ammoniacal nitrogen will undergo a further change, through the action of micro-organisms, and will be converted into the third form—that of nitrates. It is then that serious loss takes place; for nitrates cannot be retained permanently by any soil, but are lost by drainage following rain. More will be said with regard to both the absorption of ammonia by soils and the formation of nitrates, when considering the action of sulphate of ammonia.

Increase from Nitrogenous Manuring.

Seeing, then, that the natural supply of nitrogen to the soil is generally insufficient for the farmer's needs, and that loss is continually occurring, it is obvious that the supply of nitrogen in suitable form and quantity must increase the return from the land, and, indeed, must be an essential part of farm management. Both field and laboratory experiment, as well as general agricultural practice, fully bear out this conclusion. Out of the great mass of evidence as to the

* "Journal of the Royal Agricultural Society of England," Vol. XIX., S.S.

effect of nitrogenous manures, the following summary may be chosen, showing the average produce obtained from the use of nitrogen on various crops at Rothamsted; each crop being grown continually on the same land, in most cases for a long series of years.

TABLE I.

Crop.	Mineral Manures.		Ammonia Salts.		Minerals and Ammonia Salts.	
	Bushels.		Bushels.		Bushels.	
Wheat	15		$20\frac{1}{8}$		$33\frac{1}{8}$	
Barley	$22\frac{3}{8}$		29		$43\frac{1}{2}$	
Oats	$24\frac{1}{2}$		47		59	
	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.
Mangels (roots) . . .	5	2	6	6	14	13
Swedes	2	9	0	13	4	9
Potatoes	3	$7\frac{3}{4}$	1	$17\frac{3}{4}$	5	$18\frac{7}{8}$

Comparing the produce with mineral manures, which include phosphates, potash, &c., and that with mineral manures and ammonia salts, we at once see the immense gain from the use of nitrogenous manures. In the case of three of the six crops mentioned—viz., wheat, oats, and mangels—the nitrogen added to the mineral manures more than doubled the crop, and with barley it nearly doubled it.

It will be noticed, however, that the produce with ammonia salts only was not nearly so large as with mineral manures and ammonia salts together, and in two cases was below that from minerals only. Neither minerals alone nor ammonia salts alone could produce such a good crop as when they are used together. Indeed, this follows from what has been already said. The mineral manure supplies all the essential constituents of plant food except nitrogen, while ammonia salts supply nitrogen, but nothing else. Therefore, with the application of either for a series of years on the same land and crop, some essential substance will soon become deficient, and the produce will fall off in proportion. When both minerals and ammonia salts are used, however, everything necessary is being supplied, and a full crop may be obtained. It is not strictly accurate to say that the difference between the produce with minerals and that with minerals and ammonia salts is due entirely to the ammonia salts. It is rather due to both manures being able to give their full effect when used together.

In passing, it may be noticed that many misleading results have been obtained in trials of manures—particularly in field experiments—for want of proper appreciation of the interdependence of the different classes of manures.

In ordinary farm practice, however, the soil is usually more deficient in nitrogen than in minerals, and then, from the farmer's point of view, the increase shown by the addition

of a nitrogenous manure may be fairly credited to the manuring. To illustrate the effects of nitrogen on ordinary farm crops grown in rotation, the results obtained in experiments carried out in the year 1886 by the Norfolk Chamber of Agriculture, in conjunction with the Royal Agricultural Society* may be taken as fairly representative. They are as follows :—

TABLE II.

Crop.	Phosphates and Potash.				Phosphates, Potash, and Nitrogen. Average of Various Dressings.			
	Corn.	Straw.			Corn.	Straw.		
	Bush.	Cwt.	Qrs.	Lbs.	Bush.	Cwt.	Qrs.	Lbs.
Barley after swedes	44·5	25	1	26	53·93	28	0	22
Barley after wheat	34·8	18	1	17	38·59	22	2	25
	Tons.	Cwt.	Qrs.	Lbs.	Tons.	Cwt.	Qrs.	Lbs.
Swedes (average of three farms)	15	4	1	3	18	5	2	6
Mangels	17	5	3	20	21	12	0	23

In every case, a larger crop was grown where nitrogen was supplied in addition to phosphates and potash, though, as might be expected, the difference was not so great in proportion as in the Rothamsted experiments, where cropping and manuring were continually the same year after year.

In the Norfolk experiments, no plots were dressed with nitrogenous manure only. An experiment carried out at Pontefract under the direction of the Agricultural Department of the Yorkshire College in 1895 gave typical results as to the effect of nitrogenous manuring alone on swedes on ordinary farm land. Phosphates and potash gave 18 tons 2 cwt. 16 lbs. of roots per acre; with nitrogen in addition, 19 tons 12 cwt. 46 lbs.; but nitrogen alone gave only 15 tons 8 cwt. 94 lbs.—the order of the produce of different manurings being the same as that with swedes at Rothamsted. Here, then, we see that nitrogenous manures used by themselves are not to be relied on for crops grown in the ordinary course of farming, any more than under the conditions of experiment at Rothamsted. We shall have occasion to refer later to many other instances of the same thing.

Do Nitrogenous Manures Impoverish the Land?

Something must be said on the common idea amongst farmers that nitrogenous manures are exhausting to the land. Obviously, if larger crops are grown by the use of nitrogenous manures, and these crops therefore remove

* "Journal of the Royal Agricultural Society of England," Vol. XXIII., S.S., Part 1.

larger quantities of phosphates and potash, the land will be so much the poorer in those substances. If its fertility is to be kept up, they must be returned to the soil in the form of manure. But that is no reason why nitrogenous manures should be considered as mere stimulants, and not as plant food. A favourable season might equally well be considered exhausting to the land; for it produces large crops which, of course, remove more plant food from the soil than small ones would take up. With regard to lime, however, manures in which the nitrogen is in the form of salts of ammonia are exhausting; for they cause it to be carried away in the drainage from the land. This is, of course, of most practical importance on soils deficient in lime, which in other ways are less suitable for ammoniacal manures than those in which lime is abundant. The whole question as to the advisability of using nitrogenous manures becomes one of money. If the cost of the extra manures used, both to produce the crop and to compensate for the extra demands made upon the land, is greater than the increased returns that may be expected from their application, nitrogenous manures will not be remunerative. This, however, is very seldom the case on ordinary farm land, for the judicious and moderate use of nitrogenous manures enables the crops to make use of mineral matter which would otherwise lie idle in the soil.

Effect of Nitrogenous Manures on the Plant.

Having satisfied ourselves that the proper use of nitrogenous manures is advantageous, we may pass on to consider generally their action on plants.

Comparing plants grown with a full supply of nitrogen with those receiving little, the most noticeable difference is that, if all other conditions for healthy growth are fulfilled, the plants receiving nitrogen produce a much larger leaf growth of a very dark colour. The importance of this will be recognized when it is remembered that the leaves are the organs by which the plant feeds on the air—taking the element carbon from the carbon dioxide which the air contains; and that the green colouring matter, called chlorophyll, is the necessary agent in this action. The nitrogen may thus be said to increase the apparatus of the plant for the assimilation of carbon. Mineral substances are necessary for the building up of the carbon into such compounds as starch, sugar, and cellulose, which are called carbohydrates. Potash particularly seems to be needed for this purpose—an important fact, to which we shall refer again.

Another effect resulting from the use of nitrogenous manures is that the maturing of the plant is somewhat hindered, especially if the manure is applied late in the crop's growth. Provided the crop is grown early enough in the season to allow of its maturing properly, this is no disadvantage, as it gives the plant a longer time in which

to grow and collect food from the air and soil. The late application of these manures, however, is to be avoided, as we shall see later.

In this connection it is worth noticing that, in the Woburn wheat experiments, ammonia salts appeared not to delay the ripening of the crop so much as nitrate of soda.

The net effect of the increase of leaf and chlorophyll, and of the lengthened period of growth, is the apparent anomaly that a very large increase of non-nitrogenous material is produced by the use of nitrogenous manures. For example, Sir John Lawes and Sir H. Gilbert estimate a very large gain per acre in carbohydrates (starch, sugar, &c.) from manuring with nitrogen and minerals, as compared with minerals only, in all the chief crops under experiment at Rothamsted. The gain in carbohydrates for each pound of nitrogen in the manure has been as follows, on the average of several plots dressed with nitrogen in different forms and quantities per acre—

TABLE III.

Crop.	Carbohydrates per Pound of Nitrogen in Manure. Lbs.
Wheat	31·0
Barley	46·3
Sugar Beet	42·1
Mangels	29·9
Potatoes	17·0
Beans	5·5

HOW NITROGEN IS TAKEN UP BY PLANTS.

Like all the substances taken up by the roots of plants, nitrogenous matter is only useful when in a state of solution, for plants have no power of absorbing insoluble material. In this respect, sulphate of ammonia and other ammonia compounds are quite suited to the requirements of plants, being freely soluble in water.

The three forms of nitrogen in the soil differ in their usefulness to the plant. Organic nitrogen is for the most part useless, and must be regarded as a reserve which is gradually drawn upon as the nitrogen is converted into other forms. Ammoniacal and nitric nitrogen are, however, both useful to plants. Nitric nitrogen is taken up readily, and is often stored up in the plant for a time. Under favourable conditions—a suitable temperature and the presence of carbohydrates in the plant being especially necessary—it is gradually changed into various organic substances, such as amides and finally albuminoids.

Ammoniacal nitrogen may also be directly used by plants. Owing to the fact that, under natural conditions, most of a crop's nitrogen, if not the whole of it, is taken up in the nitric form, statements are frequently met with to the effect

that ammoniacal nitrogen cannot be directly used by plants. That this, however, is not the case has been shown by many investigators. A. Muntz grew various plants in a soil the only nitrogen of which was in the form of sulphate of ammonia; and though taking full precautions against nitrification, he found that the plants took up large quantities of the nitrogen.* About thirty years ago Hampe had come to the same conclusion,† but found that, in the early stages of growth, plants seemed less able to use ammoniacal nitrogen; and Wagner and others have obtained similar results. We may assume, however, that ammonia is not taken up so readily as nitric nitrogen—*i.e.*, nitrogen in the form of nitrates; and under practical conditions the ammonia of manures is almost always converted into the nitric form before being used by plants.

Though nitric nitrogen is stored up in the plant for a time, until circumstances allow of its being utilized, ammonia compounds are not to any appreciable extent, but are converted at once into a substance called asparagine. This can only be formed when carbohydrates are present. If they are deficient, compounds of ammonia act as plant poison—sulphate of ammonia perhaps least so.‡

In connection with this action, and the importance of the presence of carbohydrates in the plant when ammoniacal manures are used, it is worth repeating that mineral manures, and potash particularly, are necessary to enable the plant to form carbohydrates. The results of many experiments seem to show, as we shall see, that by withholding a full supply of potash from the soil, the action of ammonia compounds is more injuriously affected than that of other forms of nitrogenous manures.

The asparagine and other amides formed are not the final product from the nitrogen which the plant takes up. In the mature plant particularly, albuminoids are found in considerable quantities, these being formed from the amides. Among other requirements for their formation, besides those already mentioned, it is worth noticing that the presence of a sulphate is essential. As Liebig pointed out,§ sulphate of ammonia may gain in effect from this cause; but the cases in which it does so must be few, for sulphates are practically always present in the soil in sufficient quantity for the plant's requirements.

Absorption of Ammonia by Soils.

We may now pass on to consider what happens when sulphate of ammonia is applied to the soil. The actions and changes to be described take place in the same way with other compounds of ammonia, but the sulphate is the form

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* "Comptes Rendus," 109. † Vs. St., 10. ‡ Bul. Coll. Ag. Imp. Univ. Tokyo, 1895. § "Chemistry of Agriculture and Physiology." Third Ed.

almost always used as manure, and for the present concerns us most.

When first applied to the land, sulphate of ammonia, being readily soluble in water, is dissolved by the water which the soil contains. When used as a top-dressing, especially on grassland, so that it does not come into close contact with the soil, it may sometimes remain undissolved until rain falls; but the soil generally contains enough water to dissolve sulphate, if in close enough touch with it.

In a state of solution, the sulphate of ammonia spreads all through the soil; and unless some change takes place in its condition, it may be gradually washed away in the drainage from the soil. We have already referred to the fact that clay and humus in a soil have the power of fixing or absorbing ammonia; and, of course, the majority of soils contain a certain proportion of one or both of these constituents. In what way the ammonia is fixed, is not clearly understood; but it is probably chiefly by chemical combination, though capillary action may possibly assist in retaining it.

The humus and clay of the soil, however, can only absorb ammonia when it is either in the free state—*i.e.*, not combined with other substances—or in the state of carbonate. The ammonia of sulphate of ammonia must, therefore, be converted into one of these forms before it can be fixed. This is brought about by chemical action in the soil between the sulphate of ammonia and carbonate of lime, a substance which most soils contain. It will be remembered that sulphate of ammonia is a compound of ammonia and sulphuric acid, and carbonate of lime consists of lime and carbonic acid. When these two substances come into contact in the soil, an exchange takes place; the ammonia and carbonic acid combining to form carbonate of ammonia, and the lime and sulphuric acid forming sulphate of lime. That this action does really take place, is shown by the fact that after the application of sulphate of ammonia to the land the drainage water contains large quantities of sulphate of lime, and little or no ammonia.

The carbonate of ammonia thus formed can then be absorbed and fixed by the clay and humus, when it is practically safe from loss by drainage—at least, until nitrification takes place. Brustlein has shown experimentally that without the presence of carbonate of lime, absorption of ammonia does not take place when it is applied in the form of sulphate, or any other compound of ammonia except the carbonate.

The requirements for the absorption of ammonia applied as sulphate may therefore be summarized as:—

1.—The presence of enough carbonate of lime in the soil to convert the sulphate into carbonate of ammonia.

2.—The presence of clay or humus to absorb the carbonate of ammonia thus formed.

It must not be understood that these actions are immediate or complete. It is a common mistake, and one which leads to a good deal of confusion of idea, that chemical action takes place as readily and completely in the soil as in the beakers and test-tubes of the chemist's laboratory. It is really quite otherwise; and in the case we are considering, some sulphate of ammonia may remain unchanged for a long time, though the supply of carbonate of lime is plentiful. As this sulphate sinks lower and lower in the soil, most of it is gradually converted into carbonate, and is then fixed; but probably many other actions take place, though generally on a small scale and with quite unimportant results.

Possible Loss of Ammonia when Applied as Sulphate.

Carbonate of ammonia which results from the interaction of sulphate of ammonia and carbonate of lime is a very volatile substance—that is, when exposed to the air, it gradually disappears in a state of vapour, unless previously fixed by the clay or humus of the soil. It has, therefore, been suggested that, on light calcareous soils—*i.e.*, those rich in carbonate of lime, and deficient in clay and humus—serious loss of nitrogen must take place, owing to the rapid formation of carbonate of ammonia, and the want of enough absorbent material in the soil to save it from volatilization. The amount of this loss, however, has been probably exaggerated, and is hardly appreciable, except in cases where the land is particularly rich in carbonate of lime. Even then, according to Pechard,* the loss is prevented if sulphate of lime is present; for this tends to convert the ammonia in the soil into sulphate of ammonia. As to what occurs under ordinary conditions, Muntz found in an experiment on a light soil, containing 2 per cent. of lime, that the ammonia given off into the air was only at the rate of 8¾ grains (0·56 gram) per acre per day, during the first five days after a dressing of sulphate of ammonia at the rate of 4 cwt. per acre—a heavy dressing. Where farmyard manure was employed, the amount of ammonia lost in the same time was 25 grains per acre per day. These quantities are so small that they may be safely neglected in practice, especially as we may assume that the amount of ammonia given off into the air would be greatest during the first few days after the manure was applied—at any rate in the case of sulphate of ammonia. Other experiments with a variety of soils have shown even less loss of ammonia.

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* "Comptes Rendus," 109.

Nitrification.

It has been said already that though plants can make use of sulphate of ammonia and other ammonia compounds, yet they can use nitric nitrogen more easily, and do, in fact, take up most of their nitrogen in that form. Nitrification, or the process by which organic and ammoniacal nitrogen is changed into the nitric form in the soil, must therefore next be considered.

In a general way, nitrification may be described as a series of changes in which nitrogen is taken from its various compounds in the soil, and made to combine with oxygen obtained from the air to form nitric acid. Like other acids, this combines with any of the substances which the chemist calls bases, to form compounds called nitrates.

Conditions Necessary for Nitrification.

These reactions depend on the presence and activity of micro-organisms or bacteria in the soil. It has been shown by Warington* that there are two different organisms concerned in this action, one of which converts the ammonia into nitrites—compounds in which the nitrogen is combined with a smaller proportion of oxygen than in nitrates—and the other acts on the nitrites, causing their further oxidation, with the formation of nitrates. From a practical point of view, we may consider their actions as a single process; for, under the conditions existing in the soil, the two organisms are equally active. If, however, they are to cause free nitrification, the soil must be suitable for them.

In the first place, it must contain nitrogen for the organisms to convert into nitric acid. This nitrogen may be in the form of either organic matter or compounds of ammonia, the latter being more readily acted upon.

If the nitrogen is present as ammonia, there must also be organic matter in the soil to act as food for the organisms; for like other living things—both animals and plants—they only thrive when they have enough food. If the nitrogen is in the form of organic matter, the latter will, of course, serve the double purpose of supplying nitrogen and feeding the organisms.

A supply of oxygen is also necessary to enter into combination with the nitrogen, for it must be remembered that the process of nitrification consists essentially of the oxidation of nitrogen in the soil. This oxygen is, of course, derived from the air; and from this point of view the texture of the soil, and the freedom or otherwise with which the air permeates it, are highly important, by influencing the facility with which nitrification can take place.

Moisture is also essential for nitrification. Provided the soil is not water-logged, a large amount of water in the soil

* "Journal of the Chemical Society," 1891.

seems to assist the action of the nitric organisms; while if the supply is insufficient, their activity is hindered or ceases. Schlœsing obtained the following results in a long-continued series of experiments bearing on this point:—

TABLE IV.

—	I.	II.	III.	IV.
Water in soil, per cent.	9·3000	14·6000	16·0000	20·0000
Nitric acid formed per 1000 parts of soil in first thirteen months	0·1570	0·1720	0·3970	0·4780
Nitric acid formed per 1000 parts of soil in next six months	0·0289	0·0488	0·0530	0·0866

These figures show clearly that the amount of nitric acid formed is greater or less according as the soil is more or less moist. It must be noticed, however, that the amount of nitric acid formed is not in strict proportion to the amount of water in the soil, but is, on the whole, proportionately greater in the moister soils. Thus, comparing Column IV. with Column I., we see that in the former, which is little more than twice as moist, about three times as much nitric acid was formed during each of the two periods of experiment.

A certain degree of warmth is also necessary for the action of the organisms. Below a temperature of about 40° Fahr., they are practically inactive; but with greater warmth, nitrification becomes more and more rapid up to about 95° Fahr., which is the most favourable temperature. Above that, the rapidity of nitrification very soon becomes less, and at about 120° Fahr. practically ceases. Muntz found the following quantities of nitric acid formed in similar nitrifying solutions kept at the temperatures named for nearly two months:—

TABLE V.

Temperature. Deg. Fahr.	Nitric Acid Formed. Milligrams.	Temperature. Deg. Fahr.	Nitric Acid Formed. Milligrams.
41 to 46	2·3	98	98·9
57 „ 61	19·5	109	40·3
73	39·4	120	5·1
80	59·7	133	0·0
91	81·8		

There is here a steady increase in the amount of nitric acid formed, corresponding to each increase of temperature up to 98° Fahr., after which the quantity falls off rather rapidly with each further increase.

For the continued action of the micro-organisms, it is also necessary that the soil should contain some "base"—that is, some substance which can combine with nitric acid

as it is formed, taking away its acid characteristics, and producing a nitrate. If no base is present, the nitric acid accumulates in the soil; and as the organisms cannot continue their action in the presence of any acid, nitrification soon ceases. Almost invariably it is carbonate of lime which acts in this way—nitrate of lime being formed; but other bases, such as potash, are also capable of combining with the acid.

The requirements for nitrification may, therefore, be summarized as—

1.—The presence of the proper organisms.
2.—Nitrogen, either in the form of ammonia or as organic matter.
3.—Organic matter.
4.—Oxygen.
5.—Moisture.
6.—A proper degree of warmth.
7.—Carbonate of lime or some other base.

Conditions Preventing Nitrification.

The conditions adverse to nitrification which are most frequently met with are—

1.—Absence of oxygen.
2.—Absence or deficiency of carbonate of lime.
3.—Presence of acid in the soil.

The absence of oxygen from the soil may be due to the naturally close texture of the latter, as in the case of heavy clays, to imperfect cultivation in the case of arable land, or to the fact of the soil being water-logged, either from its impervious nature or from want of drainage. Whatever the cause, nitrification will cease; and under these circumstances an opposite action—denitrification—may take place, in which, under the influence of micro-organisms which are only active in the absence of oxygen, the nitrates present in the soil are destroyed and the nitrogen lost to the air in a gaseous form.

The absence of carbonate of lime, though not common, is sometimes met with. The obvious remedy is the addition of some form of lime to the land; lime, chalk, marl, and shell sand being all suitable for the purpose.

The presence of acid in the soil is usually connected with one or both of the two foregoing points. When plant refuse or other organic matter decays, various acids are formed (carbonic, humic, &c.). If there is a plentiful supply of carbonate of lime, most of these acids will be neutralized—that is, will have their acid characteristics removed by combining with it, just as we have already seen in the case of nitric acid. Even if carbonate of lime is deficient, these acids may still be washed out of the soil if the drainage is good. On the other hand, if the acids accumulate, the land becomes sour and nitrification ceases.

Rapidity of Nitrification.

Under favourable circumstances, where all the necessary conditions are fulfilled, nitrification goes on with great rapidity. Thus, in two experiments, Schlœsing obtained the following results. In each case the figures show the actual quantity of ammonia and nitric acid respectively present in 500 grams of soil, at the beginning and end of the experiment.

Table VI.

Date.	I.		II.	
	Ammonia Milligrams.	Nitric Acid. Milligrams.	Ammonia. Milligrams.	Nitric Acid. Milligrams.
June 13 . . .	55·65	..	57·00	..
July 1 . . .	5·95	186·50	6·80	206·50

In each experiment a large proportion of the ammonia present on June 13 was evidently nitrified—from 88 to 90 per cent. of it having disappeared by the end of the experiment—and in its place a large amount of nitric acid was produced. It will be noticed that the change was remarkably rapid; the whole time occupied by the experiments being only eighteen days. In a natural soil nitrification will seldom be as rapid as this; but even in ordinary cultivated land, it will often take place very quickly. For instance, the following results were obtained in an experiment on light land on the farm of the French Institute Agronomique in 1888. The amounts of ammonia and of nitric acid in the soil were ascertained on the dates mentioned on two plots, one receiving no nitrogenous manure, and the other manured at the rate of 462 lbs. cf sulphate of ammonia per acre. The results are stated per 100,000 parts of the dry soil.

Table VII.

Date.	No Nitrogenous Manure.		Sulphate of Ammonia.	
	Ammonia.	Nitric Acid.	Ammonia.	Nitric Acid.
May 8 . . .	0·32	1·08	4·94	1·08
,, 10 . . .	0·32	1·08	4·94	2·28
,, 17 . . .	0·25	1·77	3·00	6·17
June 9 . . .	..	1·63	0·65	19·22
,, 14 . . .	0·15	1·24	0·49	16·08
,, 24 . . .	..	1·03	..	9·73
July 2 . . .	0·14	0·57	0·14	1·84

As in the preceding instance the ammonia gradually disappeared from the plot manured with sulphate of ammonia, until the quantity was the same as in that rceeiving no nitrogenous manure, and nitric acid took its place. That the amount of nitric acid was not

greater at any one time is explained by the fact that heavy rain fell frequently during the course of the experiment, and washed much of it away. We may, however, safely conclude that during the season of the year when crops are growing most freely, nitrification takes place very rapidly; and, in this way, a supply of nitric nitrogen is kept up.

We have stated incidentally that, though both organic and ammoniacal nitrogen can be nitrified, yet the nitrogen of ammonia compounds is much more quickly and easily acted upon than that of organic substances. This may perhaps be explained by the fact observed by Schlœsing,* that when the necessary nitrogen is present in the form of nitrogenous organic matter, the nitrifying organism oxidizes not only the nitrogen, but also the carbon and hydrogen of the organic matter. Thus it may be said that the ferment spends part of its energy in other ways than nitrification—ways that are without beneficial influence on the plant. With compounds of ammonia, however, as the source of nitrogen, the organism exercises almost the whole of its oxidizing power on that nitrogen, only taking from organic matter the carbon necessary for its own growth and reproduction.

As influencing our choice of ammonia compounds for use as manure, it is worth noticing that sulphate of ammonia is more readily nitrified than other ammonia compounds. Schlœsing found the following to be rates at which the compounds named were nitrified under favourable conditions:—

Chloride (muriate) of ammonia .	55	lbs. of ammonia	per acre	per day.
Carbonate of ammonia	67	,,	,,	,,
Sulphate of ammonia	150	,,	,,	,,

These quantities are greater than could be expected in ordinary farm land; but they may be taken as representing the comparative speed with which nitrification takes place.

Loss of Nitrates.

We have seen that when sulphate of ammonia is applied to the soil, the ammonia is in most cases retained by virtue of the absorptive power of the soil, but that sooner or later it is nitrified—a nitrate (almost always nitrate of lime) being formed; the change taking place most rapidly in hot weather and in a somewhat moist soil.

This inevitable and often rapid change is one that must be carefully borne in mind in estimating the probable effects of a dressing of sulphate of ammonia, or indeed of any nitrogenous manure. For while most soils have more or less absorptive power for ammonia, it must be repeated that no soil has the power of holding any nitrate, except in a purely mechanical way, as a sponge may hold water.

* "Comptes Rendus," 109.

Therefore when the ammonia has been nitrified, and the resulting nitric acid has combined with carbonate of lime to form nitrate of lime, the nitrogen is then subject to serious loss by drainage after every fall of rain that occurs.

Influence of Climate and Season on the Effect of Sulphate.

The many conditions affecting nitrification, and the influence which the rate of nitrification must obviously have on the waste of nitrogen applied as sulphate of ammonia, suggest that some seasons and climates must be more suitable for this manure than others. In this connection, it is interesting to compare sulphate of ammonia and nitrate of soda. The former is rather the less soluble, and requires to undergo nitrification before it is liable to be washed out of the soil. Nitrate, on the other hand, is always subject to loss by drainage. Therefore we find in practice that sulphate of ammonia usually gives better results than nitrate of soda in a wet season, but in a dry one it is likely to remain inert in the soil, and therefore to have a relatively worse effect. As will be shown later on, in the latter case part of the unused manure may be recovered in subsequent crops.

Wet climates and wet seasons are therefore favourable to sulphate of ammonia; dry climates and seasons, to nitrate of soda. An example of this with regard to season is afforded by the Woburn wheat experiments. The following table shows the produce per acre of corn and straw in each year in which the rainfall of the growing season (April to September) was 2 inches or more either above or below the average.*

Table VIII.

Year.	Rainfall, April to September.	Ammonia Salts.				Nitrate of Soda.			
		Corn.	Straw.			Corn.	Straw.		
		Bush.	Cwt.	Qrs.	Lbs.	Bush.	Cwt.	Qrs.	Lbs.
1878	Above average.	16·7	21	1	16	11·9	19	2	0
1879	,, ,,	14·7	20	2	22	12·0	19	1	21
1882	,, ,,	32·0	31	2	22	26·0	32	0	22
1885	,, ,,	31·2	25	2	10	28·1	28	0	21
1889	,, ,,	26·3	26	1	27	18·9	23	0	2
1884	Below average.	40·3	35	1	22	31·9	29	3	10
1887	,, ,,	26·1	22	1	14	35·0	29	0	10
1890	,, ,,	24·7	19	2	15	31·2	26	3	14
Average of wet seasons		24·2	25	0	19	19·4	24	1	24
Average of dry seasons		30·4	25	3	8	32·7	28	2	11

* Voelcker, "Journal of the Royal Agricultural Society of England," Vol. IX., T.S.

This shows that while in the dry seasons (in the dry climate of Woburn, be it remarked) nitrate of soda was better than ammonia salts by about 2¼ bushels of corn and 2¾ cwt. of straw per acre, ammonia salts gave a better return in the wet seasons by about 4¾ bushels of corn and ¾ cwt. of straw per acre.

Depending upon the absorptive power of the soil and the rate of nitrification, are the two practical questions—What is the right time to use sulphate of ammonia, with reference both to season of the year and stage of growth of crops? and—Is there any valuable residue left after the first crop has been taken from the land?

Time of Year to apply Sulphate.

With regard to the former of these points, fuller knowledge has altered the ideas originally held. When it was first discovered that most soils could firmly hold ammonia applied to them, so that it was no longer liable to be washed away, it was concluded that sulphate of ammonia might safely be applied to the land in the autumn, especially in the case of an autumn sown crop, such as wheat. The extreme rapidity with which much of the nitrogen of sulphate of ammonia may be nitrified was not at the time recognized; and it was, therefore, considered an advantage to apply it to the land some time before the period of active growth in spring. Accordingly, in the Rothamsted wheat experiments the ammonia salts were for many years applied in autumn. In the course of investigations, however, as to the composition of the drainage water from land manured in various ways, it was observed that large quantities of nitrates and nitrites, chiefly of lime, were washed away during the winter from land receiving ammonia salts (equal weights of sulphate and muriate of ammonia); and, further, that the amount of nitrates and nitrites was greatest where the largest dressings of ammonia salts were employed. Later experiments proved that the serious loss of nitrates began after the application of the ammonia salts.

Table IX. shows the proportion of nitrates in the drainage water from various plots of the Rothamsted wheat experiments on the different occasions when the drains ran during the year 1881-2.*

In the season of the experiment the drains did not run after March 7 until harvest was over, so that there was no loss by drainage during the growth of the crop. But when drainage took place later in the year, loss of nitrate occurred even from the plots receiving no nitrogenous manures (Columns I. and II.). This nitrate would be produced by the nitrification of the nitrogenous matter of the roots and

* Lawes and Gilbert, "Journal of the Royal Agricultural Society of England." Vol. XIX., S. S.

other remains of previous crops. This action will probably also explain at least part, if not the whole, of the loss of nitrates where ammonia salts, spring sown, were applied in addition to minerals (Column III.), for the larger crop thus produced would, of course, leave in the soil a larger quantity of nitrogenous matter capable of undergoing nitrification.

TABLE IX.—*Nitrogen as Nitrates per Million of Water.*

Date.	I. Unmanured.	II. Mineral Manures.	III. Minerals and 400 Lbs. of Ammonia Salts Sown in Spring.	IV. Minerals and 400 Lbs. of Ammonia Salts Sown in Autumn.	V. Minerals and 600 Lbs. of Ammonia Salts Sown in Spring.
Mar. 5, 6, 7 .	3·4	3·6	3·9	11·6	5·3
Aug. 30, 6.30 a.m.	1·2	1·5	..	..	..
Aug. 30, 2 to 3 p.m.	0·9	1·4	4·1	..	..
Sept. 25 . .	4·7	6·0	..	..	..
Oct. 14 . .	6·3	8·1	..	..	..
„ 23 . .	8·7	9·5	18·5	13·1	23·0
Nov. 25 . .	5·4	6·0	9·8	66·6	17·1
„ 27 . .	7·0	7·3	11·7	40·5	18·2
Dec. 7 . .	5·1	6·3	10·9	34·8	16·8
„ 17, 18, 20, & 21	4·1	5·0	7·3	26·4	11·2
January . .	3·5	3·9	7·2	22·4	10·2

The plot receiving minerals and 400 lbs. of ammonia salts sown in autumn (Column IV.), showed a very different rate of loss by drainage. On Oct. 23, the proportion of nitrates in the drainage water was less than where the ammonia salts were spring sown, probably because smaller crops had been produced, and there was therefore less material in the soil to undergo nitrification. On Oct. 27, the ammonia salts for the following year's crop were applied; and the next time the drains ran the proportion of nitrates had enormously increased, being then higher than in any other sample of drainage water examined. All through the winter, until the end of the experiment, the quantity of nitrates, though steadily falling, remained a good deal above that washed from any of the other plots. Judging by the results obtained on March 5, 6, and 7, we may conclude that the same exceptionally heavy loss continued until the spring. When it is remembered that about 70 per cent. of the total drainage of the year occurs during the months of October to March inclusive, it will be seen what a large quantity of nitrate may thus be lost in the course of the winter.

Column V. of Table IX. is added for comparison with Column III., to illustrate the fact that has been mentioned

that the amount of nitrates lost in the drainage water was greater with increased dressings of ammonia salts.

As soon as this loss was recognized, an experiment was begun to ascertain whether the effect of the loss of nitrogen by drainage during the winter made an appreciable difference to the wheat crop. The following table shows the corn produced, in bushels, the weight of straw, and the weight of the total produce, in each case per acre, obtained by the use of ammonia salts, autumn sown and spring sown, for the years 1873-9 inclusive:—*

TABLE X.

Season.	Corn.		Straw.		Total Produce.	
	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.	Autumn Sown.	Spring Sown.
	Bush.	Bush.	Lbs.	Lbs.	Lbs.	Lbs.
1873	22	32⅝	2021	3079	3344	5031
1874	39⅜	29⅛	4645	2776	7094	4588
1875	25⅞	25½	3422	3204	5110	4915
1876	23½	25½	2212	2428	3793	4083
1877	19⅞	33⅛	1835	2788	3048	4795
1878	22⅛	31¼	3071	4952	4486	7017
1879	5⅜	16¼	906	3012	1275	4063
Average . .	22½	27¾	2587	3177	4021	4927

Autumn sowing gave the best result in only one year—1874—an exceptionally dry season; while in four years the result was as decidedly in favour of spring sowing, and in two years there was no material difference.

These experiments established the fact that ammonia salts should not be applied to the wheat crop in autumn; so in 1878 and following years they were put on to the experimental wheat crop in the spring. In 1884, a further change was adopted, one quarter of the ammonia salts being applied in autumn and the remainder in spring; and this practice has been continued since. A small quantity of nitrogen is thus at the disposal of the plant for its autumn growth; but it is not till more active vegetation has commenced in spring that the full quantity is put on. The next table [p. 24] gives the average produce of wheat in bushels per acre per annum, obtained at Rothamsted by continuously manuring with minerals only, and with minerals and ammonia salts, for each of the three periods 1852-77 inclusive, when the ammonia salts were applied in the autumn; 1878-83 inclusive, when they were put on in the spring; and 1884-94 inclusive, when one-quarter of the ammonia salts were applied in the autumn and the rest in the spring.

* Lawes and Gilbert, "Journal of the Royal Agricultural Society of England," Vol. XVI., S.S.

TABLE XI.

——	Minerals.	Minerals and Ammonia Salts.	Excess of Minerals and Ammonia Salts over Minerals only.
	Bushels.	Bushels.	Bushels.
1852 to 1877	$15\frac{5}{8}$	$33\frac{1}{4}$	$17\frac{5}{8}$
1878 to 1883	$13\frac{1}{8}$	$31\frac{1}{2}$	$18\frac{3}{8}$
1884 to 1894	$14\frac{1}{4}$	$34\frac{3}{8}$	$20\frac{1}{8}$

Too much reliance must not be placed on these figures, as the last two periods are comparatively short, and the returns may be affected by variation of the seasons. The differences, however, between the produce of the two systems of manuring—the purely mineral and the mineral and nitrogenous—probably fairly represent the comparative efficacy of the three methods of applying the ammonia salts.

We may take it, therefore, that the system of putting on a small dressing of sulphate of ammonia in the autumn, but reserving most of it until the spring, is the most economical for such a crop as wheat. The spring dressing should usually be given some time in March or early in April, so that the later spring rains may serve to distribute it through the soil.

In the case of spring-sown crops, there is no question that sulphate of ammonia should be applied in spring only, for there is no object in putting on any of it in autumn.

STAGE OF GROWTH BEST FOR THE APPLICATION OF SULPHATE.

With regard to the period of growth of the crop at which sulphate of ammonia may best be applied, everything points to the advisability of using it so as to supply nitrogen to the earliest stages of the plant's growth, as well as later. Apart from autumn-sown crops, therefore, we find that the application of sulphate of ammonia at the time of sowing the seed gives the best results. There is then a short time allowed for nitrification before the plant requires a supply of nitrogenous manure. In early spring, when nitrification is slow, it may even be sown and harrowed in a few days before the crop is sown. It has been suggested that better results would follow if sulphate of ammonia were ploughed in at the last ploughing for the crop; and in a very dry season, this might be advantageous, as the manure would be better mixed with the soil. In an average spring, however, in this country, there is usually enough rain to distribute the sulphate of ammonia through the soil; and it must be remembered that when it had been ploughed in, it would be subject to great loss from nitrification and subsequent drainage, if wet weather came on and delayed sowing.

It has also been suggested to mix the sulphate of ammonia with the seed before sowing. This, however, is risky, and likely to hinder the germination of the seed. Recent experiments of Vandevelde* have shown that substances dissolved in the water supplied to seeds often decrease the power and energy of germination; and this is, of course, exactly the state of things when the manure and seed are mixed together. The same experiments proved the important fact that, of the three groups of salts, nitrates are most injurious to germination, chlorides less so, and sulphates least harmful.

The steeping of the seed in a solution of sulphate of ammonia before sowing has been suggested; and as long ago as 1843, a communication was made to the Royal Agricultural Society† detailing most favourable results from this method. It is unsafe in practice, however; for the vitality of the seed is easily injured in this way.

Dressings of sulphate of ammonia, or of any nitrogenous manure in which the nitrogen is readily available for the plant's use, are uncertain in their action if given too late in the life of the crop.

It has been stated already that one effect of the application of nitrogenous manures is to retard the ripening of the plant. If this takes place late in the crop's life, its growth may go on so long that, in the case of a corn crop, it ripens badly, and in late districts the harvest is put off till the comparatively unfavourable weather of the late autumn; or, in the case of roots, the crop has to be taken up or fed in an immature condition, when, of course, its feeding value is less than it should be.

Another effect of the use of nitrogenous manures will be remembered—viz., the increased formation of leaf. In the case of a late dressing, this result is exaggerated, much of the energy of the plant being consumed in this way, and the amount and quality of the seed being deteriorated. Following as a secondary result from this rankness of growth, is the great tendency of corn crops to go down or be laid, when they have been dressed with nitrogenous manures late in the season of growth. Such crops are also more likely to be injured by rust and mildew, or blight.

It is worth while to point out here that the unfavourable effects mentioned are not the result of the late application of sulphate of ammonia only, but are common to all kinds of concentrated, readily available, nitrogenous manures. In fact, sulphate of ammonia is on the whole less likely to do harm to the crop, even when used injudiciously, than nitrate of soda.

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* Bot. Centr., 69.

† Campbell, "Journal of the Royal Agricultural Society of England," Vol. IV.

Use of Sulphate on Different Soils.

The time and manner of application which enables sulphate of ammonia to give its best results will, however, depend a good deal on the soil treated. On light sandy soils, which have little power of holding manure of any kind, and in which nitrification takes place rapidly, sulphate should be applied just when the plant needs the nitrogen—that is, when growth is just beginning. Two, or even three, small dressings will also give better results than the same quantity of the manure put on at one time. By carrying out these principles, the crop will have the opportunity of using a larger proportion of the nitrogen, and less will be washed away.

On heavy land, the exact reverse is the case; for such soil has great power of holding ammonia, is not well adapted for nitrification, and is so impervious to water that nitrates, even when formed, are washed away comparatively slowly. There is, therefore, less risk of loss, and the sulphate of ammonia may be applied rather before the crop needs it, and all at one time.

Soils containing a large proportion of lime are in their texture and physical properties generally similar to light sandy land. There is, however, the difference already mentioned—that there is more risk of loss of nitrogen to the air in the form of carbonate of ammonia from calcareous soils than from others. It has been shown that this loss, in the case of most soils, is extremely small, and, it may be added, even from calcareous soils need generally be considered only when the usual plan of top-dressing is adopted. Less loss will generally occur when the sulphate of ammonia is ploughed or harrowed in—at least if care be taken to apply it a short time only before the seed is sown. Altogether, these exceptionally calcareous soils are not so well adapted for the use of quick-acting ammoniacal manures as either light or heavy land.

On the other hand, soils deficient in lime, whether they are of vegetable or mineral origin, are also unsuited for the use of sulphate of ammonia. This will be understood from what has been said as to the important part lime plays with regard to the absorptive power of soils and the process of nitrification, and need not be gone into more fully. It may be added, however, that soils which are poor in lime often contain large quantities of nitrogen in an organic form. When this is the case, there is obviously greater economy in bringing this nitrogen into action by liming, &c., than in applying nitrogenous manures.

What has been said with regard to the action of sulphate of ammonia on different soils, must be taken as applying directly to soils of extreme composition—exceptionally sandy, clayey, or calcareous. All the soils between these

extremes—that is, the great majority—may be dressed with sulphate with good results. The above remarks, however, indicate the general principles which must govern the mode of application, according as the character of the soil approaches most nearly to one or other of the extremes mentioned.

Residue from Sulphate of Ammonia.

On the question whether any valuable residue is left after the first crop has been removed, some difference is found in the evidence afforded by different experiments. In both the Rothamsted and the Woburn wheat experiments, special attention has been paid to the point. At the former experimental station, plots have been manured with mineral manures alone and with ammonia salts alone in alternate years. Thus, when the mineral manures are applied, there is abundance of mineral matter, and any residue that may be left from the previous year's dressing of ammonia salts; while when ammonia salts are used, there is a full supply of nitrogen and the residues left from the last mineral manuring. On the heavy land at Rothamsted, the mineral manures with residues of ammonia salts gave, on the average of forty years, 15¼ bushels of wheat per acre, against 15 bushels on land which had received mineral manures only each year of the same period. This seems to show that, on the soil experimented with, there is practically no valuable residue.

It should be noticed, however, that for the first twenty-four years of the experiment, the crop grown with minerals and residues of ammonia was rather better in proportion to that obtained by the use of minerals alone, though, it will be remembered, the ammonia salts were at the time applied in the autumn, and therefore were not giving their full effect.

At Woburn, on comparatively light land, an experiment carried out on similar lines, except that mineral manures were applied every year, gave rather different results. On the average of fifteen years, the following results were obtained with sulphate of ammonia and nitrate of soda respectively :—

Table XII.

Manures.	Ammonia Salts.	Nitrate of Soda.
	Bushels.	Bushels.
Minerals and nitrogenous manures.	37·2	34·0
Minerals and residue of previous year's nitrogenous manures . .	23·1	16·4

The average produce of the land continuously manured with minerals only was 14·4 bushels for the same period.

The results, therefore, show that the residue left after the removal of the first crop is capable of producing an increase of about $8\frac{3}{4}$ bushels per acre when ammonia salts are used, and of 2 bushels with nitrate of soda.

The difference between the Rothamsted and the Woburn results is difficult to account for; but it may perhaps be explained by the difference of soil, and by the fact that at Woburn minerals were applied every year, but at Rothamsted only in alternate years. The shorter duration of the Woburn experiments may also influence the result; for at Rothamsted, as we have noticed, at first the residues of ammonia salts had some effect.

It may be safely concluded, however, that a considerable residue from ammonia salts may remain in the soil after the removal of the first crop. It is probable that much of this is in the form of nitrogenous organic matter, such as roots and stubble left by the crop, which gradually decays and undergoes nitrification. A part, however, seems in the Woburn experiments to have been left untouched by the first crop, and to have remained in its original state in the soil; for the residue left by the ammonia salts gives its greatest effect in the year following an under-average crop obtained with a direct dressing of nitrogenous manure. For instance, the following results were obtained in the wheat experiments at Woburn in 1895 and 1896, the former of which years was exceptionally dry, and therefore prevented the full action of the ammonia salts. It will be remembered that mineral manures were applied every year to each plot.

TABLE XIII.

Plot.	Nitrogenous Manure.	1895.	1896.
8A	Ammonia salts .	Applied, 17·2 bush.	Omitted, 26·9 bush.
8B	,, ,, .	Omitted, 17·0 ,,	Applied, 30·5 ,,
9A	Nitrate of soda .	Applied, 20·1 ,,	Omitted, 12·0 ,,
9B	,, ,, .	Omitted, 13·4 ,,	Applied, 25·9 ,,

In 1895, it will be seen that the application of ammonia salts on plot 8A gave practically no larger return than the mere residue from the previous year's manuring on plot 8B. But the ammonia salts which failed to act in that year gave an extra return in 1896; the yield on plot 8A in the second year being within about $3\frac{1}{2}$ bushels of plot 8B, to which in 1896 ammonia salts were directly applied. We see from this that, if ammonia salts are not used by the crop to which they are applied, a considerable proportion may remain in the soil for the use of succeeding crops. Moreover, this residue must be to a great extent in its original state; for if it consisted only of roots and other plant refuse, we should find that when the nitrogenous

manure produced a small crop (which would, of course, leave comparatively little organic matter in the soil), the residue would also produce little effect. But the exact opposite of this occurred in the above experiment. A dry season on the light soil at Woburn may interfere with nitrification during the hottest part of the year, when normally it takes place most rapidly. If this happens, the washing away of nitrogen in the form of nitrate during the autumn will be comparatively small.

The comparison given in Table XIII. between ammonia salts and nitrate of soda is important, because it illustrates one marked difference in the action of these two principal nitrogenous manures. The figures relating to nitrate of soda show clearly that if this manure is not used by the crop to which it is applied, it will be practically lost; for on plot 9A, though in the dry year of 1895 the crop was a good deal under the average obtained by the direct application of nitrate, in 1896 the residue gave a crop below the average of those obtained from such residues. (See Table XII.) On the other hand, the residue of the ammonia salts, under the same conditions, produced a crop 3·8 bushels above the average.

Effect of Applying too much Sulphate.

Passing on from this question, a word must be said with regard to the effect of different quantities of sulphate of ammonia on crops. All the injurious effects arising from the use of nitrogenous manures too late in the season—such as the late ripening of the crop, the over-production of leaf and poor yield of grain, &c.—may also be produced by their application in too large quantity. In both cases, it must be observed, the injury is done, not by any unsuitability of the manures for use on the farm (a conclusion too often arrived at from very insufficient evidence), but by their use in an injudicious manner.

The quantities of sulphate of ammonia usually suitable for the chief farm crops will be mentioned later, when the crops are considered in detail. For the present, however, it must be noticed that no absolute rule can be laid down as to the quantity of any manure that will give the best results. Soils and seasons differ enormously; and the effect of manures varies in proportion. Even in the case of similar soils and seasons, differences in condition of the former may cause different results from any dressing of manure. The benefit arising from the use of nitrogenous manures on barley after wheat, and the injury they do to barley after roots fed off by sheep, is a good example of this.

The effect of the application of a given quantity of sulphate of ammonia or other nitrogenous manure, depends also on whether the crop has a plentiful supply of the

mineral substances it requires. If not, a comparatively small dressing of the nitrogenous manure is likely to produce all the possible injurious effects to an exaggerated degree. If, on the other hand, all the essential mineral substances are in abundance, a comparatively large dressing of nitrogenous manure will only stimulate a strong but healthy growth, and will therefore prove remunerative. A balance or proportion between the mineral and nitrogenous manures is the important thing. Failure to realize this is one of the common causes of unsatisfactory results from the the use of nitrogenous manures, and is chiefly responsible for the exhaustion of the soil which sometimes follows their use.

Effect of Sulphate of Ammonia on the Soil.

The effect of sulphate of ammonia on the soil must also be mentioned. In explaining the action of the soil in absorbing ammonia, it has been stated that when sulphate of ammonia comes into contact with carbonate of lime in the soil, carbonate of ammonia and sulphate of lime are produced, of which the last named is washed away in large quantities in the drainage water. Loss of lime, therefore, follows the use of sulphate of ammonia. Under any conditions likely to arise in ordinary farm practice, this will not be of much consequence, except on soils specially deficient in lime. Even then an occasional liming will supply all the lime required, and will in any case be useful or even necessary to the soil, quite apart from the effects of sulphate of ammonia. In long-continued experiments in continuous cropping and manuring, however, such as those at Rothamsted and Woburn, where in some cases very large dressings of ammonia salts are given every year, the soil after a time shows clearly the effects of this removal of lime. It becomes very sour, and the crops grown become unhealthy. For instance, in the Woburn permanent barley experiments, the average produce per acre from the use of ammonia salts, which, in the first three periods of five years each, had been 36·6 bushels, 42·2 bushels, and 34·5 bushels per annum respectively, fell to 21 bushels per annum for the fourth period—the sixteenth to the twentieth years of the experiment—a proportionately greater falling off than occurred on the plots where ammonia salts were not employed.

When a soil has thus been robbed of its lime, it becomes like one naturally deficient in that constituent—its absorptive power for ammonia is injured, and nitrification may be stopped for want of a base to combine with the nitric acid as it is formed. We must repeat, however, that these extreme effects are not likely to result under the usual management of a farm, in which sulphate of ammonia is only used occasionally, and in comparatively small quantities.

Sulphate of ammonia is not alone among the artificial manures in causing injury to the land when used continuously in excessively large quantities. On heavy land, nitrate of soda injures the texture of the soil, by increasing its power of retaining moisture. On clay land this change soon becomes appreciable, even under farming conditions, so that among farmers nitrate of soda is reputed to make clay plough up "like liver," sodden and wet, and work with difficulty. For example, in the experiments on continuous oat growing at Rothamsted, the plots dressed with nitrate of soda had become so retentive of moisture by the sixth year that it was found impossible to work the land properly, and very irregular crops were produced in consequence.

Method of Applying Sulphate.

The practical difficulty of applying a small quantity of sulphate of ammonia (sometimes less than a hundredweight per acre), so as to spread it evenly over the surface, and the unevenness of crop that results unless this is done, naturally suggests the advisability of mixing the manure before sowing with two or three times its own bulk of something that will serve to dilute it, so to speak—that will add to its bulk without adding to the nitrogen it contains. It is then easier to distribute the sulphate of ammonia evenly; and any trifling irregularity in the sowing no longer causes harmful differences in the crop.

Sand, ashes, and salt are all commonly used, and all serve their purpose, provided they are in dry condition, and are mixed with the sulphate of ammonia just before use. Salt, however, is often damp, or even if dry when mixed with the sulphate, it will become damp rapidly by taking up moisture from the air. Hence the importance of mixing just before use; for it need hardly be said that, if the mixture be damp, the difficulties of even sowing are greatly increased.

Thorough mixing of the manure and ashes, or whatever may be used, is important, though sometimes neglected; for it is obvious that, without care in this respect, there can be no gain in evenness of sowing.

Where other manures are to be applied at the same time, they are frequently mixed with the sulphate of ammonia, instead of any such comparatively inert substances as those mentioned above. This plan answers the required purpose quite well, provided that such substances as kainite, &c., which take up water from the air, and might therefore spoil the condition of the mixture for sowing, are only mixed in at the last moment before use, and are themselves in a dry state. The suitability of sulphate of ammonia for mixing with other substances is taken advantage of by manufacturers of compound manures, who employ it very largely as a source of nitrogen for corn, grass, and other manures. It compares favourably in this respect with nitrate of soda,

which becomes damp when mixed with other manures, and spoils the condition of the mixture.

An important exception must be made in the case of manures containing lime or carbonate of lime. Any such manure—as, for instance, Thomas phosphate or basic slag—if mixed with sulphate of ammonia will cause a considerable amount of ammonia to be given off into the air, especially during the mixing and sowing. Carbonate of lime is less active in this respect, but may cause an appreciable loss—particularly if the mixture is damp. It may be added that nitrate of soda suffers no loss of nitrogen in this way by contact with lime.

Composition of Sulphate of Ammonia.

In the pure state sulphate of ammonia has the chemical formula $2NH_4,SO_4$, implying that two atoms of nitrogen, eight of hydrogen, one of sulphur, and four of oxygen are united in it. Expressed by weight, its composition is :—

Nitrogen	21·21 per cent.
Hydrogen	6·06 ,, ,,
Sulphur	24·24 ,, ,,
Oxygen	48·48 ,, ,,

As it is usually sold, sulphate of ammonia of good quality is of from 95 to 97 per cent. purity—that is, 95 to 97 per cent. is actual sulphate of ammonia; the remainder consisting chiefly of moisture, with any earthy or other impurity that may have become accidentally mixed with it. Such manure will contain from 20·15 to 20·57 per cent. of nitrogen.

For trade purposes, nitrogenous manures are usually described as containing a certain percentage of ammonia, though in many cases their nitrogen is not in that form. This is merely a conventional way of expressing the amount of nitrogen present. It has been said that there are fourteen parts of nitrogen by weight in ammonia and three of hydrogen. Therefore fourteen-seventeenths of the weight of ammonia consists of nitrogen. Similarly, if a manure contains 14 per cent. of nitrogen, it will be described as having 17 per cent. of ammonia.

In the case of sulphate of ammonia, therefore, containing 20·5 per cent. of nitrogen, the amount of ammonia equivalent to this will be $20{\cdot}5 \times \frac{17}{14}$, or almost exactly 24·9 per cent. In deciding upon the relative economy of using one nitrogenous manure or another, and in comparing market quotations, it is important to bear in mind the distinction between nitrogen and ammonia, and the numerical relationship (14 : 17) which exists between them.

Cost and Valuation of Sulphate.

It cannot be too clearly understood that it is only the nitrogen that is of value in sulphate of ammonia. Hydrogen, oxygen, and sulphur are all necessary for plant growth, it is true; but they are supplied so freely by natural means that there is never any need to apply them as manure. We may therefore fairly consider that the whole price paid for sulphate of ammonia is given for the nitrogen; and we can thus easily find out what the nitrogen costs per pound. For instance, a recent quotation for sulphate of ammonia is £10 2s. 6d. per ton, containing 24 per cent. of ammonia. A ton will contain $2240 \times \frac{24}{100} = 537{\cdot}6$ lbs. of ammonia, equal to 442·7 lbs. of nitrogen. The price of ammonia in the manure is, therefore, £10 2s. 6d. ÷ 537·6 = 4½d. per lb.; and of nitrogen, £10 2s. 6d. ÷ 442·7 = 5½d. per lb.

Calculations of this kind may be used for comparing one manure with another. For instance, nitrate of soda contains about 15·65 per cent. of nitrogen, equal to 19 per cent. of ammonia; that is 350·5 lbs. of nitrogen per ton, equal to 425·6 lbs. of ammonia. The price at the time of writing is about £7 15s. per ton, at which price nitrogen costs £7 15s. ÷ 350·5 = 5⅓d. per lb.; and ammonia, £7 15s. ÷ 425·6 = 4⅓d. per lb.

A more usual way of comparing the cost of nitrogen in different manures, and a more convenient one, is by calculating the cost of nitrogen or ammonia per unit—that is, the price per ton of the manure for each 1 per cent. of ammonia or nitrogen. For instance, in the example taken above the sulphate of ammonia is said to contain 24 units of ammonia or 19¾ units of nitrogen. The price per unit of ammonia is therefore £10 2s. 6d. ÷ 24 = 8s. 5¼d.; while a unit of nitrogen costs £10 2s. 6d. ÷ 19¾ = 10s. 3d. Similarly, the nitrate of soda is said to contain 15·65 units of nitrogen, or 19 units of ammonia; the price of the former being nearly 9s. 11d. per unit, that of the latter 8s. 2d. per unit. In actual working, this system of estimating the cost per unit is very simple and helpful in comparing the relative costs of manures; for by it, and taking into account also the suitability of two manures for any given purpose, we can decide on their comparative economy. It will be easily realized that nitrogen is sometimes cheaper in one manure, sometimes in another, according to variations in the market quotations. Very often one comes across a tendency to buy a manure because it is at a low price per ton; but this may not be the cheapest manure. The cost per unit of nitrogen, or whatever of value the manure contains, may be greater than that in another manure at a higher price per ton.

At the prices mentioned above, it will be seen that nitrogen in sulphate of ammonia is slightly more expensive than in

nitrate of soda. The reverse of this is often the case, owing to variations in prices; and, indeed, for some years sulphate of ammonia has been generally the cheapest source of nitrogen in the market—the price per unit of nitrogen having been as a rule lower (sometimes as much as 20 per cent. lower) than in any other manure supplying nitrogen in a condition equally ready for the use of crops.

Impurities and Adulterants.

Good samples of sulphate of ammonia generally contain little impurity except moisture, with a very small amount of sandy matter, some free acid, and often still less common salt. In impure specimens, however, the proportion of both earthy impurity and of common salt is sometimes considerable. The well-known test of putting a little of the sulphate of ammonia on a red-hot shovel, shows their presence; for the sulphate of ammonia disappears as a vapour, leaving the impurities behind. A good sample will, therefore, leave practically no residue when tested in this way. Sulphate of soda, and sometimes sulphate of iron also, are occasionally found, being used as adulterants; but their presence is, of course, detected by the same test.

Now and then cases are reported in which sulphate of ammonia is put on the market containing considerable quantities of free sulphuric acid (oil of vitriol). It need hardly be said that such manures are harmful to crops, and should be avoided.

An even worse impurity—though a comparatively rare one—is the thiocyanate or sulphocyanate of ammonia, which is one of the products from the distillation of coal in the manufacture of gas. It is so powerful a poison to plants that even a few pounds per acre of it in a dressing of sulphate of ammonia will do great damage to the crop. The thiocyanate is easily detected by adding a solution of ferric chloride to a solution of the manure, when, if it be present, a deep red colour will appear.

At one time, arsenic was not uncommonly found in sulphate of ammonia—derived from the impure acid used in its manufacture; but it is now rarely present.

Effect of Sulphate on Individual Crops.

Having dealt with the general facts and principles connected with the use of sulphate of ammonia, we will next consider its action upon the chief farm crops, as shown by the results of experiments. As nitrate of soda is the only other manure practically comparable with sulphate of ammonia, we will, where possible, compare the action of the two substances.

WHEAT.

Like all other plants of the natural order Gramineæ—that is the cereals and grasses—wheat benefits to an exceptional extent from the judicious application of nitrogenous manures. This is not due to any special requirement of nitrogen on the part of the members of this order, but probably to the comparative difficulty they have in obtaining it—owing perhaps to their habit of root development, or in many cases to the season of the year when their most active growth takes place. Both corn and straw are largely increased by nitrogenous manuring.

Sulphate for Continuous Wheat Growing.

Experiments in continuous cropping and manuring are important as indicating with far greater certainty than rotation experiments the characteristic results of applying particular manures to particular crops. In the experiments on continuous wheat growing at Rothamsted, the following results per acre per annum have been obtained, on the average of forty years, 1852 to 1891 inclusive :—

Table XIV.

Manuring.	Corn.		Straw.
	Bushels.	Weight per Bushel.	
		Lbs.	Cwt.
No manure	13	58¼	10⅝
Mineral manure only	15	58⅞	12⅜
Ammonia salts = 86 lbs. of nitrogen.	20⅛	57¼	18¼
Nitrate of soda = 86 lbs. of nitrogen*	22¾	56⅝	23⅜
Ammonia salts and minerals . . .	33⅛	59¾	33⅜
Nitrate of soda and minerals* . . .	35⅜	59	39⅝

* Nitrate of soda = 43 lbs. of nitrogen only, applied in last seven years.

These figures are a good example of the usual relative increase yielded under the different systems of manuring. Mineral manures alone (sulphates of potash, soda, and magnesia, and superphosphate of lime) gave little increase compared to the unmanured plot ; and the plots receiving nitrogenous manures only, though producing more than that receiving minerals only, were yet far behind those manured with both minerals and nitrogen. Another important point is that with nitrogenous manures only—that is, when the soil was well supplied with nitrogen, but was deficient in the other constituents of plant food—the weight per bushel of corn was diminished. This almost certainly implies that the quality and value of the corn was less than on the unmanured plot. As a matter of fact, the average weight per bushel on the two plots manured with nitrogen only was lower than under any other system

of manuring experimented with. On the other hand, where minerals were supplied with nitrogen, the quality of the grain, as indicated by the weight per bushel, was a good deal higher than that of the unmanured plots.

It is, however, with the comparison afforded between ammonia salts and nitrate of soda that we are at present most concerned. It must be remembered that these two manures were used so as to supply the same amount of nitrogen to the crop, not in equal weights of the manures themselves. Thus, 400 lbs. per acre of ammonia salts were compared with 550 lbs. per acre of nitrate of soda. This must be clearly remembered, as it is important in drawing conclusions from the experiments as to the relative economy of different manures. In all experiments to be quoted comparing the action of sulphate and nitrate, the same quantity of nitrogen was applied per acre in the two forms, except where it is distinctly stated that equal weights of the manures were used.

In the Rothamsted experiments, nitrate of soda gave the larger increase; but the weight per bushel of the corn was distinctly lower than that produced by ammonia salts, whether the manures were used alone or with minerals. The proportion of grain to straw is also worth noticing, for generally a crop giving a large proportion of straw is more liable to be laid before harvest, and in many seasons to suffer from blight. Averaging the two plots dressed with ammonia salts, there was 181 lbs. of straw to each 100 lbs. of grain; but with nitrate of soda, there was on the average 210 lbs. of straw to each 100 lbs. of grain.

In the experiments carried out at Woburn on continuous wheat growing, similar results were obtained on the average of twenty years. The following was the return per acre per annum with the manures mentioned :—

TABLE XV.

Manuring.	Corn.		Straw.		
	Bushels.	Weight per bush.			
		Lbs.	Cwt.	Qrs.	Lbs.
No manure	15·3	57·3	15	0	9
Mineral manures	15·1	57·8	15	2	13
Ammonia salts = 50 lbs. of ammonia	23·8	57·3	23	1	20
Nitrate of soda = 50 lbs. of ammonia	23·6	55·2	23	2	27
Ammonia salts = 50 lbs. of ammonia and minerals . .	30·2	58·7	29	0	6
Nitrate of soda = 50 lbs. of ammonia and minerals . .	31·2	57·8	31	1	13
Ammonia salts = 100 lbs. of ammonia and minerals* . .	37·2	58·7	36	3	18
Nitrate of soda = 100 lbs. of ammonia and minerals* . .	34·0	57·0	38	0	6

* Nitrogenous manures applied in alternate years.

These results are very similar to those obtained at Rothamsted, but are more favourable to the use of ammonia salts. When the nitrogenous manures were used alone, ammonia salts and nitrate of soda gave practically equal yields. With minerals, a moderate dressing of ammonia salts gave one bushel per acre less than nitrate of soda; but when double the amount of each of the nitrogenous manures was given, ammonia salts produced over three bushels more than nitrate of soda. The lower weight per bushel of the corn grown with nitrate was even more marked than in the Rothamsted experiments, especially when used alone or in the heavier dressing with minerals. It should also be noticed that where moderate dressings of the nitrogenous manures were given with minerals, the extra weight per bushel of the corn produced by ammonia salts partly compensated for the smaller quantity; the difference in the total weight of corn between the two nitrogenous manures being only about 30 lbs. per acre. The lower proportion of straw to grain with ammonia salts is also seen—though not so markedly as at Rothamsted, except with the heavy dressings of the nitrogenous manures, where the additional quantity of nitrate applied seems to have been used by the crop chiefly in the formation of straw.

As bearing on the quality of the wheat grown with different manures, it is interesting to notice the relative values of the wheat grown on the various plots at Woburn, in the twenty-first year of experiment—1897.* The values per quarter fixed by practical valuers were—

TABLE XVI.

No manure	37s.	0d.	per qr.
Minerals only	37	0	,,
Ammonia salts = 50 lbs. of ammonia	37	0	,,
Nitrate of soda = 50 lbs. of ammonia	35	0	,,
Ammonia salts = 50 lbs. of ammonia and minerals	38	6	,,
Nitrate of soda = 50 lbs. of ammonia and minerals	36	0	,,
Ammonia salts = 100 lbs. of ammonia and minerals*	38	6	,,
Nitrate of soda = 100 lbs. of ammonia and minerals*	36	6	,,

* Nitrogenous manures applied in alternate years.

The average value of the corn from the three plots receiving ammonia salts was 38s. a quarter, against an average of 35s. 10d. on the plots receiving nitrate of soda—that is, ammonia salts raised the value of the corn 1s. a quarter above the produce of the unmanured plot, but nitrate reduced the value to 1s. 2d. below that of the unmanured corn. These values refer to one season only; and therefore too much stress must not be laid upon them. But they are probably fairly representative; being confirmed by the

* "Journal of the Royal Agricultural Society of England," Vol. IX., Third Series, Part 3.

weight per bushel of the corn, recorded over a long series of years both at Rothamsted and at Woburn, and by similar results which will be noticed in connection with other crops.

For wheat, therefore, the results of these experiments seem to show that there is not much difference in the bulk of the corn produced by a given amount of nitrogen in the manure, whether in the form of ammonia salts or nitrate of soda; but the quality of the corn is distinctly better from ammonia salts. Both at Rothamsted and Woburn, the average rainfall is lower than in many parts of the country; and therefore the results obtained are perhaps on that account more favourable to nitrate than would be the case in moister climates.

The amount of straw, on the other hand, is greater with nitrate of soda, though any advantage in this is counterbalanced by the crop's greater liability to be laid, and less power to resist mildew. If too much nitrogen be applied, either in comparison to the mineral plant food present in the soil, or to the plant's requirements, harm is more likely to result when nitrate is used than with ammonia salts.

Sulphate for Wheat in Rotation.

As to the best way of using sulphate of ammonia for wheat under the conditions of ordinary farming, some light is afforded by the experiments of the Norfolk Chamber of Agriculture in 1888.* These were carried out at three centres; but the results of two stations only will be considered at present, for at the third—Flitcham—no mixture of manures which did not contain potash was effective, so that the inclusion of its results would only serve to mask those of the other two stations for our present purpose. The following table shows the average yield per acre at the two stations, Whitlingham and Cawston:—

Table XVII.

Manuring.	Corn.	Straw.
	Bush.	Cwt. Qrs. Lbs.
1 cwt. sulphate of ammonia, sown in autumn .	23·92	17 2 16
2 cwt. sulphate of ammonia, sown in autumn .	23·13	16 2 19
2 cwt. sulphate of ammonia, half sown in autumn, half in spring	24·93	18 0 2
No manure	22·67	16 1 14

In the first place, as explaining the small increase obtained by any of these manurings, it should be mentioned that the season was on the whole unfavourable to their

* "Journal of the Royal Agricultural Society of England," Vol. XXV., S. S., Part 1.

action, and that in the district where the experiments were carried out, farmyard manure seems necessary to produce a full crop of wheat. The actual increase obtained by the various dressings of nitrogenous manures is, therefore, less than would be usually obtained. Comparing the yields of the different plots, however, we see that the limit of economy was reached for autumn sowing at 1 cwt. per acre of sulphate of ammonia; 2 cwt. giving less corn and less straw than 1 cwt. When half the sulphate was applied in the spring, better results were obtained, as would be expected from what has already been said on this point.

One point should be mentioned in connection with the results obtained at Flitcham, the station not included in the above table. It will be remembered that the soil here was remarkably deficient in potash, so that without potash manuring other artificials gave a very small return; but with potash they gave a comparatively large increase. The results afford a very good example of the fact already noted, that the presence of potash seems particularly important if sulphate of ammonia is to produce its full effect; for that manure gave relatively worse results at Flitcham than at the other two stations—Whitlingham and Cawston—in the soils of which available potash was comparatively plentiful.

In experiments with wheat carried out on sterile sand, Pagnoul has found the same thing.* When a complete manure was supplied, there was little difference in the results obtained from the two manures; but if potash were deficient, nitrate was twice as effective as sulphate. In a second year's experiment,† he found that, while the addition of potash to nitrate increased the yield in the proportion of 13 : 10, potash with sulphate increased it as 26 : 10. The weight of individual grains of corn was increased by potash with nitrate in the proportion of 14 : 10, and with sulphate of ammonia in the proportion of 17 : 10.

A possible cause of the less favourable effect of sulphate of ammonia when potash is deficient has been mentioned already—viz., the need of potash for the formation of carbohydrates, and the importance of carbohydrates in the plant for the formation of asparagine from the nitrogen of ammonia salts, preparatory to the further formation of albuminoids, &c. The nitrate of soda, also, may perhaps give its better effect under these conditions, by the soda of the manure taking the place of potash to some extent in the plant, and so partially supplying the deficiency. The evidence on this point is conflicting; but the results obtained by some investigators seem to make this explanation possible.

The Rothamsted wheat experiments have already been

* "Comptes Rendus," 111. † "Ann. Agron," 17.

quoted to show that the best way to apply ammonia salts is to put on a small part of the dressing in the autumn, and the rest—about three-quarters—in spring. Another question arises as to whether the spring dressing should be put on at one time or in several applications. It is generally known that nitrate of soda gives a better return when applied in two or three dressings. Should sulphate of ammonia be used in the same way? An early experiment at Rothamsted answers this question as far as heavy land is concerned. In the wheat experiments of 1845, two plots were manured with ammonia salts—one receiving all the manure at one time in the early spring, the other in four different dressings. The results were as follows:—

Table XVIII.

	Corn.			Straw.	
	Bush.	Pks.		Lbs.	Per 100 of Corn.
Ammonia salts in one dressing . .	33	1½	..	4058	190
,, ,, in four dressings. .	31	3¼	..	4266	215

There was evidently an advantage in applying the whole of the manure at once. The lower yield of grain, the increase in straw, and the large increase in the amount of straw per 100 of grain, all showed that with four dressings part of the manure had been applied too late in the growth of the crop. As already mentioned, very light soils form a possible exception to the rule of applying all the sulphate at once.

Practically a dressing of about 1 cwt. of sulphate of ammonia per acre will generally be found enough for wheat grown in rotation. If the crop be very weak and thin after the winter, a rather heavier dressing—up to 2 cwt. as a maximum—may be given; while on the other hand, if the land be in high condition, ¾ cwt. or even ½ cwt. will be better.

BARLEY.

Effect of Sulphate on Yield.

For this crop, we find that nitrogenous manures are even more effective than for wheat. Otherwise the differences between the two crops are not very important. We will first consider the use of sulphate of ammonia with reference to the yield only. At Rothamsted, Sir John Lawes and Sir Henry Gilbert obtained the following results per acre per annum on the average of forty years' experiments in continuous barley growing:—

TABLE XIX.

Mineral Manures.	No Nitrogen.		Ammonia Salts.		Nitrate of Soda.	
	Corn.	Straw.	Corn.	Straw.	Corn.	Straw.
	Bush.	Lbs.	Bush.	Lbs.	Bush.	Lbs.
No mineral manure . . .	16½	1044	29	1793	32¾	2127
Superphosphate	21¾	1210	42¾	2674	45¾	3018
Sulphates of potash, soda, and magnesia	18	1076	31⅜	2011	33½	2322
Superphosphate and sulphates of potash, soda, and magnesia	22⅜	1279	43½	2904	45½	3186

The increase from the nitrogenous manures, even when applied alone, was considerable, while with minerals in addition heavy crops were obtained. The relative importance of superphosphate with the nitrogenous manures, and the small effect from the additional use of potash and other minerals, must be noticed. Thus while superphosphate and either of the nitrogenous manures gave a crop about half as large again as the nitrogenous manure alone, the sulphates of potash, soda, and magnesia yielded with nitrate of soda only ¾ bushel more corn than the nitrate alone, and with ammonia salts 2⅜ bushels more. In the same way, the addition of potash and other minerals to superphosphate and nitrate caused a decrease of ¼ bushel of corn; and where the nitrogen was in the form of ammonia salts there was an increase of ¾ bushel. This is another instance, though not a very marked one, of the relative importance of potash with ammonia salts, and the slight or even injurious effect of its use with nitrate of soda.

Passing on to compare the effects of ammonia salts and of nitrate of soda, we see that the latter, whether used by itself or with mineral manures, gave somewhat the higher yield. The higher proportion of straw from nitrate is probably on the whole a disadvantage, as making the crop more likely to be laid—an effect more injurious to the value of barley than to that of wheat.

In the Woburn experiments, the results are similar to those obtained at Rothamsted. It will be remembered, however, that the crops manured with ammonia salts became markedly unhealthy towards the end of the first twenty years of experiment; owing probably to the continual loss of lime from the soil, occasioned by the use of ammonia salts in considerable quantity year after year.

One result not shown by the Rothamsted experiments must be noticed. On plots at Woburn dressed annually with minerals and in alternate years with nitrogenous

manures, a marked difference was shown between barley and wheat. In the case of wheat, it will be remembered that, while mineral manures and the residue from the application of nitrate of soda to the previous crop gave only 2 bushels increase over the mineral manures alone, the residue from ammonia salts gave about 8¾ bushels increase. (See Table XII.) In the case of barley, the residues of the two nitrogenous manures gave practically identical results, as will be seen in the following table, giving the average produce per acre per annum from the manures mentioned for the first fifteen years of experiment. The yield from mineral manures only was 22·6 bushels for the same period.

TABLE XX.

	Ammonia Salts.		Nitrate of Soda.
Minerals and nitrogenous manures	44·9	..	50·1
Minerals and residue of previous year's nitrogenous manures	31·0	..	31·1

It should be observed that, in these experiments, the residue from ammonia salts was as effective on barley as on wheat; but the residue from the previous application of nitrate of soda was more effective on barley than on wheat.

On farms worked in the ordinary way, sulphate of ammonia gives precisely similar returns compared to nitrate of soda as in the continuous experiments mentioned. For example, in an experiment carried out in 1887 by the Norfolk Chamber of Agriculture at Whitlingham, ¾ cwt. of sulphate of ammonia with minerals gave exactly the same return of corn as 1 cwt. of nitrate with minerals, and rather more straw; double the quantity of nitrate gave much better results; while doubling the sulphate yielded no additional crop. It must be remembered, however, that 1887 was a remarkably dry year, and would therefore favour the action of nitrate of soda, and would also preserve the crop from any likelihood of suffering from the larger dose of nitrate.

EFFECT OF SULPHATE ON QUALITY.

So far the yield per acre only has been considered; but the quality of the grain for malting purposes is more important from an economical point of view than the mere quantity. The quality of barley is, however, a thing upon which it is difficult to obtain accurate statistics, and one which can hardly be expressed by figures. Unlike wheat, the weight per bushel of which is an approximate index of quality, the weight per bushel of barley is a secondary matter. Of course, other things being equal, a high weight per bushel is desirable; and in this respect sulphate of ammonia and nitrate of soda have the same relative effect on barley as on wheat—sulphate giving grain of greater weight than nitrate. In both the Rothamsted and the Woburn experiments this is shown; the average weight per bushel being about ½ lb. greater with sulphate than with nitrate.

But this is a comparatively unimportant matter ; for the maturation of the grain is the chief factor controlling its malting quality. It has been pointed out that nitrogenous manures in general delay the ripening of the crop ; and accordingly we find that they cannot be used in large quantity without spoiling the sample. It will be remembered that this action is less noticeable in the case of sulphate of ammonia than with nitrate of soda, and where there is a full supply of minerals than where they are deficient. We should expect, therefore, that a better malting sample of grain would be produced by the use of sulphate of ammonia than by nitrate of soda, particularly when minerals were also freely supplied ; and we shall see that this is the case.

An inquiry was carried out by Tanner* some time ago on this subject, which led him to the conclusion that sulphate of ammonia improves the quality of barley for malting, while nitrate of soda invariably makes it worse.

More recently, Munro and Beavan† have published the results of an examination of the barley grown at Rothamsted under various conditions of manuring for twenty-four years (1872 to 1895). Though from the long storage of many of the samples an accurate valuation was impossible, it was found that they could be divided into four classes—viz., those in which the grain was—

1.—Over average in maturation and size.
2.—Over average in maturation, under average in size.
3.—Under average in maturation, over average in size.
4.—Under average in maturation and size.

The following table shows the number of times in the twenty-four years that each manure produced barley of each of the above classes. The arrangement is in the order of their malting quality.

TABLE XXI.

Manures.	Number of Samples in Each Class. (I)	(II.)	(III.)	IV.)
Ammonia salts, superphosphate, and alkaline salts	18	2	4	0
Superphosphate	15	5	3	1
Nitrate of soda, superphosphate, and alkaline salts	13	6	5	0
Nitrate of soda and superphosphate	9	10	2	3
Superphosphate and alkaline salts	10	3	8	3
Ammonia salts and superphosphate	6	9	3	6
Unmanured	6	6	9	3
Alkaline salts.	5	1	11	7
Ammonia salts and alkaline salts	3	2	10	9
Ammonia salts	2	4	8	10
Nitrate of soda	2	4	5	13
Nitrate of soda and alkaline salts	1	2	8	13

* "Journal of the Bath and West of England Society," Third Series, Vol. XIII.

† "Journal of the Royal Agricultural Society of England," Vol. VIII., Third Series.

From this we see that barley grown with ammonia salts with superphosphate and alkaline salts (sulphates of potash, soda, and magnesia) was of higher average malting quality than that produced by any other manuring, producing grain of the highest class in eighteen years out of the twenty-four considered, and was distinctly better than nitrate of soda with the same mineral manures. When the alkaline salts were omitted, nitrate gave a better average sample than ammonia salts—another instance of the importance of a sufficiency of potash and other similar substances when ammonia salts are used. In both the other applications of the nitrogenous manures—that is, by themselves and with alkaline salts—the ammonia salts were distinctly better than nitrate of soda in their effect on the quality of the corn.

The unfavourable influence of nitrate of soda is perhaps due to, or correlated with, its tendency to produce a large proportion of straw, with which is usually found coarseness of the husk enveloping the grain, and a greater proportion of tail corn. Both these points correspond closely with the malting quality as shown in the above table. The following is the average proportion of grain per 100 of straw, and of tail corn per 100 of total grain, from plots at Rothamsted receiving ammonia salts and nitrate of soda, alone and with mineral manures, for the forty years 1852 to 1891.

TABLE XXII.

Manures.	Grain per 100 Straw.	Tail Corn per 100 Total Grain.
Ammonia salts, superphosphate, and alkaline salts	85·0	3·9
Nitrate of soda, superphosphate, and alkaline salts	81·4	4·9
Ammonia salts and superphosphate	90·7	5·3
Nitrate of soda and superphosphate	86·0	5·0
Ammonia salts and alkaline salts	88·0	5·7
Nitrate of soda and alkaline salts	81·5	6·5
Ammonia salts	91·2	6·6
Nitrate of soda	86·7	7·0
Average of four plots receiving ammonia salts	88·7	5·4
Average of four plots receiving nitrate of soda	83·9	5·8

In each pair of plots the proportion of grain to straw was higher with ammonia salts than with nitrate of soda; and in each case, except where superphosphate only was added to the nitrogenous manures, the percentage of tail corn was lower with ammonia salts.

To sum up the matter with regard to barley, sulphate of ammonia gives a large increase in the crop; and though this is somewhat less on the average than that obtained from nitrate of soda, yet the gain in quality will generally more than make up for the smaller return. On a crop so liable to be injured by over-manuring, the use of sulphate of ammonia for barley after a sheepfold would, of course, almost always be harmful; but no practical man needs to be told that. After wheat, however, or roots drawn off the land, or under

any conditions that impoverish the soil, a dressing of from ¾ cwt. to 1 cwt. per acre is useful and economical. On very hungry or poor land, up to 1½ cwt. may be given with effect. In all cases of manuring barley with sulphate of ammonia, it is important to remember the need of the crop of minerals, both phosphates and potash. These may be present in the soil, either as a natural constituent or as a residue from previous manuring; but if not, they must be supplied as manure, or the sulphate cannot give its full effect.

OATS.

With regard to this crop, there are no records available of experiments carried out over long series of years—such as the wheat and barley experiments at Rothamsted and Woburn. At the same time, the evidence we have on the effect of sulphate of ammonia on oats is so free from contradictions or anomalies, that we need have no hesitation in accepting the conclusions arrived at.

At Rothamsted, experiments on the continuous growth of oats were carried out from 1869 to 1878; but after the first five years, the plots dressed with nitrate of soda became so wet that the crop was badly got in, and the plant was therefore irregular. Taking, therefore, the first five years only, the average results obtained were as follows per acre per annum:—

TABLE XXIII.

Manures.	Dressed Grain.		Total Straw.
	Quantity.	Weight per Bushel.	
	Bushels.	Lbs.	Cwt.
Unmanured	19⅞	33¾	10⅜
Mineral manures*	24½	35	13⅜
Ammonia salts	47	35⅞	28½
Ammonia salts and mineral manures*	59	37	41⅛
Nitrate of soda	47⅛	35⅓	27½
Nitrate of soda and mineral manures*	57½	35¾	35

* Mineral manures are in all cases sulphates of potash, soda, and magnesia, and superphosphate.

Without minerals, ammonia salts and nitrate of soda gave almost identical results; but when minerals were given in addition, the difference in the quantity of grain, though slight, was in favour of ammonia salts, as was also the weight per bushel. A somewhat unexpected point was the larger proportion of the straw to the grain produced by the ammonia salts.

If we were to include with the above the yields of the last four crops, obtained in the five years 1874 to 1878 inclusive, the average result would be much more in favour of ammonia

salts compared with nitrate of soda; but, as already explained, these years do not furnish such a fair comparison of the action of the two manures.

Other investigators have obtained similar results. Thus Baessler* found, in experiments on a sandy humous soil, that sulphate of ammonia applied to oats gave a yield of grain about equal to that from nitrate of soda; phosphates being supplied in both cases. He found, however, that nitrate produced more straw. Rhodin†, on the average of two years, found sulphate of ammonia distinctly better than nitrate of soda in its results on oats grown on heavy clay.

Amongst experiments carried out on oats grown in rotation on ordinary farms, we may take as typical those conducted by the Glasgow and West of Scotland Technical College on a number of farms in the south-west of Scotland in each of the years 1894 and 1895. The following table gives a summary of the average results per acre, as far as they concern our present subject :—

TABLE XXIV.

Manures.	1894. 13 Farms.		1895. 15 Farms.		Average. 1894-5.	
	Corn.	Straw.	Corn.	Straw.	Corn.	Straw.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
No manure.	1375	2867	1358	2654	1366	2760
Sulphate of ammonia, 88 lbs.	1803	3859	1683	3110	1743	3484
Nitrate of soda, 1 cwt. . .	1749	3847	1473	3000	1611	3423
Sulphate of ammonia, 88 lbs.; superphosphate, 2 cwt. .	2018	4132	1812	3017	1915	3574
Nitrate of soda, 1 cwt.; superphosphate, 2 cwt. . . .	2004	4203	1763	3159	1883	3681
Sulphate of ammonia, 88 lbs.; superphosphate, 2 cwt.; muriate of potash, 1 cwt. .	2091	4396	1891	3139	1991	3767
Nitrate of soda, 1 cwt.; superphosphate, 2 cwt.; muriate of potash, 1 cwt. . . .	1999	4257	1716	3141	1857	3699

The results of these experiments are very consistent. The increase obtained from all the manures was greater in the wet season of 1894 than in the dry one of 1895; but the average produce of the different plots was in each year in the same order. In every case the plots dressed with sulphate of ammonia—whether used alone, with superphosphate, or with superphosphate and muriate of potash—gave a larger yield of corn than the corresponding plots receiving nitrate of soda. Also when used either alone or with superphosphate and muriate of potash, sulphate of ammonia produced more straw than nitrate of soda; but

* "Bied. Centr.," 1889.

† "Exper. Stat. Record," 4.

with superphosphate only in addition to the nitrogenous manures, the reverse was the case. It must also be noticed that in each year nitrate of soda with superphosphate produced a rather better effect than the same manures with muriate of potash in addition. On the other hand, the addition of muriate of potash to sulphate of ammonia and superphosphate raised the yield of both straw and grain. Thus, again, we see the different effect of potash manures with nitrate or sulphate of ammonia.

In each year the most productive plot was that manured with sulphate of ammonia, superphosphate, and muriate of potash, not only of those plots included in Table XXIV., but of others also which were in the scheme of the experiments. Whether this manuring would prove most economical, would, of course, depend on the market price of the manures and of produce. In any calculation on this subject, it is well to remember that the quality of grain is likely to be distinctly better when sulphate of ammonia is used than with nitrate of soda.

In view of the common practice of top-dressing corn crops with nitrogenous manures alone, when any top-dressing is given, it is interesting to note the large increase obtained by the use of mineral manures in addition. On the average of the two years, the gain is equal to about 6 bushels of corn and $2\frac{3}{4}$ cwt. of straw per acre.

In passing, it may be noticed that these experiments seem to explain an apparent discrepancy between the results obtained at Rothamsted and those of Baessler quoted above. It will be remembered that at Rothamsted, ammonia salts and mineral manures gave a larger yield of straw than nitrate and mineral manures; while Baessler found the opposite to be the case. In the latter experiments, however, phosphates only were given in addition to the nitrogenous manures. Turning to the Scotch experiments, we find both these results confirmed; ammonia salts yielding most straw when phosphates and potash were supplied, nitrate when phosphates only were added.

As a general rule, a dressing of $\frac{3}{4}$ cwt. to $1\frac{1}{2}$ cwt. per acre will give the best results in practice, though more than 1 cwt. will only be required when the land is in poor condition. Even in the case of ordinary farm land, the addition of minerals to the nitrogenous manure will on the average give a largely increased crop; about 2 cwt. per acre of superphosphate, and the same quantity of kainite, being suitable amounts to apply; or basic slag might be used in place of the superphosphate.

MANGELS.

In considering the results of experiments on this and other similar crops, we are met with a difficulty in estimating the economical effect of manures, because the composition, and

consequently the feeding value, of the roots is affected very greatly by differences in manuring. As the root crops are in the great majority of cases grown for consumption on the farm, it is the feeding value rather than the market value that must be taken into account.

Effect of Sulphate on Yield.

At Rothamsted, as far as weight of roots per acre is concerned, nitrate of soda gave better results on mangels grown continuously on the same land than ammonia salts. The following table gives the weight of roots per acre per annum on the average of seventeen years—1876 to 1892—produced by the manurings mentioned :—

Table XXV.

Standard Manures.	Alone.		With Nitrate of Soda.		With Ammonia Salts.	
	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.
Farmyard manure	15	10	21	8	21	1
Farmyard manure and superphosphate	15	15	22	8	20	6
Superphosphate	4	15	14	14	8	1
Superphosphate and sulphate of potash	4	5	14	16	13	9

These figures again illustrate the principles we have noticed in the case of the corn crops. The addition of nitrogenous manure gave in each instance a large increase; and again we see that, while superphosphate and nitrate of soda give about the same return as those manures with potash in addition, when ammonia salts take the place of nitrate, potash manuring seems essential for a full crop.

Effect of Sulphate on Feeding Value.

When the amount of food for stock per acre is considered, we find different results according to the treatment of the crop as regards farmyard manure. As mangels are comparatively seldom grown without farmyard manure, and as it is well established that they make use of it as well as, or better than, any other crop, we will first deal with the feeding value of the crops at Rothamsted to which farmyard manure was applied. The most important food constituent of the crop is sugar, the percentage of which, and quantity produced per acre, on the plots manured with farmyard manure, on the average of four years, 1877 to 1880, are given in the following table.

TABLE XXVI.

—	Alone.		Nitrate of Soda.		Ammonia Salts.	
	Sugar per Cent.	Sugar per Acre.	Sugar per Cent.	Sugar per Acre.	Sugar per Cent.	Sugar per Acre.
		Lbs.		Lbs.		Lbs.
Farmyard manure . .	8·04	2358	6·69	2916	7·20	3409
Farmyard manure and superphosphate . .	8·10	2487	6·42	3069	6·80	3179

The addition of the nitrogenous manures to the others reduced the percentage of sugar in the roots, especially in the case of nitrate of soda; but the increase in the weight of the crop more than counterbalanced this, so that the weight of sugar per acre is increased. The largest quantity of sugar per acre is produced by farmyard manure and ammonia salts; being 340 lbs. greater than the highest produce of sugar obtained with nitrate of soda—viz., that from nitrate, farmyard manure, and superphosphate. Even the smaller quantity of sugar produced by ammonia salts, farmyard manure, and superphosphate, was still 110 lbs. per acre higher than the best yield from nitrate of soda.

We may conclude, therefore, from this that with farmyard manure ammonia salts produce more feeding material per acre than nitrate of soda, though the weight of the crop may be less.

Without farmyard manure, the opposite is the case; nitrate giving the largest amount of food per acre. The following table shows the percentage and quantity per acre of sugar, on the average of the plots at Rothamsted dressed with superphosphate and sulphate of potash, and with a complete mineral manuring, the minerals alone, and with nitrogenous manures in addition :—

TABLE XXVII.

Manures.	Sugar.	
	Per Cent.	Per Acre.
		Lbs.
Mineral manures alone	9·52	957
Do. and nitrate of soda	7·18	2740
Do. and ammonia salts	8·18	2487

The figures given are the averages of four years—1877-80. This shows clearly the superiority of nitrate of soda for mangels where no farmyard manure is used; for the produce of sugar per acre is 253 lbs. greater than from ammonia

salts. But, as has been already pointed out, mangels grown without farmyard manure form only a small proportion of the whole area under the crop, so this superiority of nitrate of soda is relatively unimportant.

Sulphate for Mangels in Rotation.

These results obtained at Rothamsted are fully confirmed by many other experiments carried out on farms in all parts of the country. For example, in an experiment of the Norfolk Chamber of Agriculture in 1886,* on light loam at Whitlingham, on mangels grown without farm manure, a given quantity of nitrogen as nitrate of soda gave a distinctly greater weight of roots than sulphate of ammonia.

In the same year, the experiments of the Essex Agricultural Society, in which farmyard manure was used, showed an average advantage in weight of roots of only 14 cwt. per acre from the use of nitrate of soda, compared with sulphate of ammonia; and from what we have seen of the Rothamsted results, it is probable that the actual feeding value in this case would be in favour of sulphate of ammonia.

A good deal of difference of opinion exists amongst farmers as to whether nitrogenous manures should be applied to mangels with the seed or as a top-dressing later. The experiments of the Essex Agricultural Society referred to above, throw light on the question. Taking the results of strictly comparable plots, we obtain the following averages :—

Table XXVIII.

	Nitrogen applied with Seed.				Nitrogen applied in July.		
	Tons	Cwt.	Lbs.		Tons	Cwt.	Lbs.
Average of nitrate of soda plots . . .	24	12	54	..	25	3	56
Average of sulphate of ammonia plots.	24	17	2	..	23	11	8

There is not very much difference shown here, except that evidently sulphate of ammonia should be applied at seed time, and not as a top dressing later in the year. Nitrate, on the other hand, was somewhat more effective as a top dressing than when sown with seed.

Judging from the results of experiments, therefore, we may conclude that when farmyard manure is used sulphate of ammonia will yield, on the average, an almost equal weight of roots per acre, compared with the produce of nitrate of soda—particularly if there is also a plentiful supply of phosphates and potash, either in the soil or in the manures used. The feeding value per acre is also probably higher when sulphate of ammonia is employed than with nitrate of soda. Without farmyard manure, nitrate is

* "Journal of the Royal Agricultural Society of England," Vol. XXIII., S.S., Part I.

probably superior to sulphate of ammonia, both in yield per acre and in feeding value.

From 1 to 2 cwt. per acre applied at seed time is a good dressing in practice, with farmyard manure, 3 or 4 cwt. of superphosphate, and 2 cwt. of kainite. These quantities are, of course, variable according to soil and other conditions.

TURNIPS AND SWEDES.

Following the order adopted in considering other crops, the experiments at Rothamsted on the continuous growth of swedes, from 1856 to 1871, may first be examined. The manuring of the plots was not absolutely the same all through the experiment; nitric acid and sawdust being used in place of nitrate of soda for the first five years. For the sake of brevity, however, we will speak of these plots as receiving nitrate of soda.

The following table shows the weight of roots per acre per annum produced by various manures:—

TABLE XXIX.

Manures.	Alone.		With Ammonia Salts.		With Nitrate of Soda.	
	Tons.	Cwt.	Tons.	Cwt.	Tons.	Cwt.
Farmyard manure	6	4	8	8	7	9
Do., and superphosphate	6	7	8	5	7	13
Unmanured	0	11	0	13	0	19
Superphosphate	2	12	3	16	4	13
Superphosphate each year, and sulphate of potash for first five years.	2	7	4	5	4	11

The results are somewhat similar to those already noticed in the case of mangels. With farmyard manure, ammonia salts were undoubtedly more effective than nitrate of soda; while without farmyard manure, nitrate was in every instance superior to ammonia salts in the weight of roots it produced. The effect of potash, when used with superphosphate and a nitrogenous manure, was just what we have seen so often with regard to other crops—tending, if anything, to diminish the yield when nitrate was used, but increasing it with ammonia salts.

Passing on to experiments on turnips grown under ordinary farm conditions, an important series, carried out in Banffshire,* under the direction of the Highland and Agricultural Society, in 1893-4, may be taken as an example. The following are the results, so far as they concern the present subject, obtained on the various plots for each of the years of experiment. The results of 1893 are the

* "Transactions of the Highland and Agricultural Society," Vols. VI. and VII., Fifth Series.

average of 25 experiments where artificials only were used, and of 15 where farmyard manure was also employed. Those of 1894 are the averages of 22 and 16 experiments respectively.

TABLE XXX.

—	1893.		1894.		Average.	
	With Sulphate of Ammonia.	With Nitrate of Soda.	With Sulphate of Ammonia.	With Nitrate of Soda.	With Sulphate of Ammonia.	With Nitrate of Soda.
	Tons. Cwt.	Tons. Cwt.	Tons. Cwt.	Tons. Cwt.	Tons. Cwt.	Tons. Cwt.
Bone meal . .	18 17	17 15	17 5	15 7	18 1	16 11
Superphosphate	21 16	20 7	18 13	18 0	20 4	19 3
Bone meal and farmyard manure . .	22 2	20 19	17 12	18 1	19 17	19 10
Superphosphate and farmyard manure . .	24 4	23 7	18 1	19 17	21 2	21 12

In 1893, with each kind of additional manure, sulphate of ammonia gave distinctly better results than nitrate of soda; and in 1894, sulphate was also more efficient when used with artificials only. With farmyard manure, however, contrary to what we should expect, nitrate gave a better return, so that on the average of the two years it yielded half a ton more roots with superphosphate and farmyard manure, though with bonemeal and farmyard manure it was still 7 cwt. inferior to sulphate of ammonia. This is another example of the comparatively better effect of superphosphate and nitrate than of superphosphate and sulphate. It is unfortunate that this series of experiments did not include plots dressed with potash; for it would have been interesting to see whether, as with other crops, the addition of potash to the other manures would have increased the yield where sulphate was used to a greater extent than with nitrate.

The effect of season has much to do with the question of the relative economy of sulphate of ammonia and nitrate of soda on the turnip crop. Thus, in a similar experiment to the above, carried out in the year 1892*—not included with the results of 1893-4 because the manurings tested were not exactly similar—sulphate of ammonia with bone meal gave 10 cwt. more roots than nitrate; but with superphosphate, nitrate produced 9 cwt. more than sulphate, a result less favourable to sulphate of ammonia than those of 1893-4.

* "Transactions of the Highland and Agricultural Society," Vol. V., Fifth Series.

Another interesting comparison was afforded by the experiments of the Norfolk Chamber of Agriculture in 1886* with swedes. The following were the weights of roots grown on the different plots named per acre on the average of three farms:—

TABLE XXXI.

Mineral Manures.	Alone.			With 1¼ Cwt. Sulphate of Ammonia.			With 1½ Cwt. Nitrate of Soda.		
	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.
Superphosphate, 4 cwt.	14	2	97	17	5	56	16	14	74
Do. with sulphate of potash, 2 cwt. . . .	15	4	31	18	14	19	18	8	48

The effect of potash with superphosphate and nitrate of soda was rather greater than we have seen in other instances. Sulphate of ammonia, however, whether with or without potash, gave a larger weight of roots than nitrate.

One more instance may be quoted as showing how the relative effects of sulphate and nitrate vary according to the manures with which they are used. The following results were obtained as the average of two experiments carried out in 1897 under the direction of the Yorkshire College. The figures relating to rape dust are included for comparison :—

TABLE XXXII.

	With ¾ Cwt. Sulphate of Ammonia.			With 1 Cwt. Nitrate of Soda.			With 3 Cwt. Rape Dust.		
	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.
Farmyard manure, 15 tons; kainite, 4 cwt. .	19	17	6	19	8	84	18	3	104
F. M., 15 tons; K., 4 cwt.; superphosphate, 3 cwt.	20	1	8	21	4	48	20	1	48
F. M., 15 tons; K., 4 cwt.; bone meal, 5 cwt. . .	20	15	80	20	1	48	20	1	8
F. M., 15 tons; K., 4 cwt.; basic slag, 6 cwt. . .	18	2	16	19	17	56	17	15	80
F. M., 15 tons; K., 4 cwt.; dissolved bones, 4 cwt.	23	4	72	19	3	24	20	9	32
F. M., 15 tons; K., 4 cwt.; superphosphate 2 cwt.; bone meal, 2 cwt. . .	22	3	64	19	15	40	20	11	48
F. M., 15 tons; superphosphate, 2 cwt.; bone meal, 2 cwt. . .	20	1	8	18	5	40	19	17	20
Average . . .	20	12	20	19	13	80	19	11	48

* "Journal of the Royal Agricultural Society of England," Vol. XXIII., S.S., Part I.

On the average, the seven plots dressed with sulphate of ammonia produced about a ton per acre more roots than the nitrate plots; and the rape dust plots were about equal to the latter. Looking at the results of the individual plots, we see that in only two cases out of the seven did nitrate give a higher yield than sulphate. Of these one was the plot receiving superphosphate, which confirms what we have already noticed; and the other was the basic slag plot, where possibly some of the nitrogen of the sulphate of ammonia may have been lost through the action of the lime of the slag. The high produce of sulphate of ammonia with dissolved bones, compared with nitrate is worth noticing; for the results of many experiments seem to show that the use of dissolved bones with sulphate of ammonia gives particularly good returns.

In ordinary farm practice, the use of sulphate of ammonia adds very much to the weight of the crop, and to the extent of about 1 cwt. per acre may be relied on to repay its cost and leave a profit. As we have seen with other crops, potash manuring seems peculiarly helpful to its action. The sulphate should be applied at the time of sowing, and will generally be found to give particularly good results in seasons in which growth goes on late in the year. It has been noted by many experimenters that turnips grown with sulphate of ammonia are more healthy, and keep better, than those grown with nitrate. This is to be expected from what we have already said as to the effect of the manures on the rankness of growth of all crops.

POTATOES.

The Rothamsted experiments naturally claim first attention with this, as with the other crops we have dealt with. For the first twelve years of experiment in the continuous growth of potatoes on the same land, the following were the average weights of potatoes of different qualities per acre per annum, and the percentage of diseased tubers produced by various manurings.*

TABLE XXXIII.

	Good.		Small.		Diseased.		Total.		Diseased in Total.
	Tons.	Cwt.	Ton.	Cwt.	Ton.	Cwt.	Tons.	Cwt.	Per Cent.
Unmanured . . .	1	13½	0	5	0	1¼	1	19¾	3·15
Mineral manures .	3	7¾	0	4⅞	0	2⅝	3	15¼	3·45
Minerals and ammonia salts . .	5	18⅞	0	7¼	0	8⅜	6	14½	6·26
Minerals and nitrate of soda . .	5	17⅝	0	6⅜	0	9¼	6	13	7·00

* "Agricultural Students Gazette," New Series, IV., 2.

Compared with the corn crops, we see here a relatively large increase from the use of mineral manures alone; but still the nitrogenous manures gave a large further increase. The produce is slightly higher with ammonia salts than with nitrate of soda, both in total weight and in good marketable potatoes.

The figures relating to disease are also interesting. As would be expected, the proportion of diseased potatoes is higher in the heavier crops grown by the use of nitrogenous manures; but it is important to notice that the crops grown with nitrate were, on the average, more diseased than those with ammonia salts. This, however, harmonizes with what we know of the effects of the two manures on plant growth generally.

Some interesting experiments were carried out by Voelcker in 1868 and 1869, on the growth of potatoes in rotation.* In each year the experiment was carried out on two farms. The following table gives the average results per acre in each of the two years, and on the average of both:—

TABLE XXXIV.

Manures.	1868.			1869.			Average.		
	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.	Tons.	Cwt.	Lbs.
Unmanured	4	10	33	6	11	56	5	10	100
Superphosphate and potash salts	7	5	100	8	5	2	7	15	51
Superphosphate, potash salts, and sulphate of ammonia	9	0	106	10	4	49	9	12	77
Superphosphate, potash salts, and nitrate of soda	7	9	12	9	11	110	8	10	61
Farmyard manure	8	9	51	9	17	21	9	3	36

The potash salts were in some cases crude potash salts, and in others muriate of potash. Equal weights—2 cwt. per acre—of sulphate of ammonia and nitrate of soda were used; so that the sulphate plots received more nitrogen than those dressed with nitrate.

The average results of the two years are very similar, and to a great extent repeat what we have seen in the Rothamsted results. But most noticeable is the superiority of sulphate of ammonia used with superphosphate and potash salts, not only over nitrate of soda with the same minerals, but to a less extent over farmyard manure.

The two artificial nitrogenous manures gave similar results in an experiment carried out in Anglesey in 1893, by the University College of North Wales, on a poor, free-working soil on a clay subsoil. In this case, also, equal weights of the manures were employed—1 cwt. per

* "Journal of the Royal Agricultural Society of England," Vol. VI., S.S.

acre—so that the sulphate of ammonia supplied more nitrogen than the nitrate of soda by about 5 lbs. per acre. The following were the weights of potatoes grown per acre:—

TABLE XXXV.

Manures.	Alone.	With Sulphate of Ammonia.	With Nitrate of Soda.
	Tons. Cwt. Lbs.	Tons. Cwt. Lbs.	Tons. Cwt. Lbs.
Superphosphate, 3 cwt.; sulphate of potash, 2 cwt.	..	8 17 96	4 14 32
Farmyard manure, 15 tons; superphosphate, 3 cwt.; sulphate of potash, 2 cwt. . . .	8 7 16	10 14 13	9 15 0
Average . . .	..	9 15 110	7 4 72

The difference in favour of sulphate of ammonia when artificials only were used is remarkable, and is possibly partly due to accidental circumstances. That an actual superiority of sulphate of ammonia was shown in this experiment, may be inferred from the fact that the highest produce of any of the plots—many of which are not included above—was that from sulphate of ammonia with farmyard manure and minerals. Nitrate of soda was used in a number of different combinations, but at best gave a crop nearly 7 cwt. worse than the best sulphate crop.

So as to avoid giving a partial view of the case, one other experiment may be quoted. This was carried out on two farms in Cumberland and Durham, in 1896, under the direction of the Durham College of Science. The artificial nitrogenous manures, it must be noticed, were employed so as to give equal quantities of nitrogen, not in equal weights of the manures. The following are some of the results obtained:—

TABLE XXXVI.

Manures.	Large.	Small.	Total.
	Tons. Cwt.	Ton. Cwt.	Tons. Cwt.
Unmanured	4 15	0 10½	5 5½
Farmyard manure, 12 tons	8 1½	0 17	8 18½
F.M., 12 tons; superphosphate, 5 cwt.; kainite, 5 cwt.	7 15¾	0 19	8 14¾
F.M., 12 tons; S., 5 cwt.; K., 5 cwt.; nitrate of soda, 1½ cwt.	9 2	0 11¾	9 13¾
F.M., 12 tons; S., 5 cwt.; K., 5 cwt.; sulphate of ammonia, 1⅛ cwt. . .	9 1¼	0 13	9 14¼
F.M., 12 tons; S., 5 cwt.; S.A., 1⅛ cwt.	9 8¾	0 11¾	10 0½
F.M., 12 tons; K., 5 cwt.; S.A., 1⅛ cwt.	8 18¾	0 15¼	9 14

With a full mineral manuring, sulphate of ammonia and nitrate of soda gave practically equal results. More exceptional, however, is the fact that the omission of kainite from the full manuring containing sulphate of ammonia caused a distinct increase in the produce. Possibly a lighter dressing of kainite would have given a better return than either the amount applied or the total omission of potash manure.

The composition of potatoes grown with various manures is chiefly important to the farmer when they are to be used for feeding stock. It is, however, worth mentioning that, just as we have seen with mangels, that the amount of sugar produced per acre is greater by manuring with ammonia salts than with nitrate of soda, when farmyard manure is also applied to the crop, so with potatoes we find that the chief feeding material they contain—starch—is formed in larger quantity per acre with ammonia manures than with nitrate. The amount of starch per acre per annum in the crops on some of the plots at Rothamsted, on the average of ten years—1876 to 1885—was as follows:—

Table XXXVII.

No manure	1,120	lbs. starch
Mineral manures	1,988	,,
Minerals and ammonia salts	3,436	,,
Minerals and nitrate of soda	3,368	,,

The difference between the two plots receiving nitrogenous manures, though not very large—68 lbs. of starch per acre—is still distinctly in favour of ammonia salts.

Comparing all the evidence at our disposal, we may safely conclude that, in practice, sulphate of ammonia will prove the best nitrogenous manure for potatoes, and will often give highly remunerative results. The quantity used will, of course, vary according to the condition of the land and the other manures employed; but it should usually be between 1 and 2 cwt. per acre.

BEANS.

This plant is a member of the natural order Leguminosæ, and, like other leguminous plants, has the special power already noticed of obtaining the nitrogen it requires from the air by means of the bacteria in the nodules on its roots. As we should expect, therefore, it benefits less from the application of nitrogenous manures than any of the other crops we have noticed. The number of field experiments with beans bearing on our subject is small, and may be dealt with in few words.

In experiments on the continuous growth of beans, Sir John Lawes and Sir Henry Gilbert found that nitrate of soda produced greater effect than ammonia salts, but that mineral manures were more important than either in their

influence on the yield. In opposition to this, Hellriegel* found sulphate of ammonia more effective on the leguminous crops generally than nitrate of soda.

On the whole, however, the conclusion cannot be avoided that no nitrogenous manure will prove economical for application to beans; and the subject need not be further discussed.

CLOVER.

With this leguminous plant, as with beans, nitrogenous manures are often of little use; but the evidence afforded by experiment is not quite so consistent as in the case of beans.

In an early experiment at Rothamsted, the average produce of red clover hay per acre, from six plots, manured in various ways, or left unmanured, was 4 tons 7 cwt. 76 lbs.; while six similar plots, receiving exactly the same manures, but with the addition of ammonia salts to each, only averaged 4 tons 4 cwt. 3 lbs.—a falling off of about 3½ cwt. On the other hand, in the attempted continuous growth of clover at Rothamsted, the produce of hay per acre on the average of the seven crops grown in 29 years was, with mineral manures only, 4171 lbs. per acre, and with mineral manures and nitrogenous manures in addition, 4555 lbs. per acre—a gain of about 3½ cwt. from the use of the nitrogenous manures.

Somewhat more favourable results have sometimes been obtained. For instance, Von Knieriem† found, on the average of two seasons, an increase in the clover crop of 52 per cent. by the use of sulphate of ammonia and superphosphate, against 30 per cent. increase with superphosphate only. In the former case, the benefit of the manuring extended into the second year; but with superphosphate only, no effect was perceptible after the year of application.

The general conclusion arrived at as the result of experiment is that, though nitrogenous manures often give an appreciable increase when applied to the clover crop, yet they are very uncertain in their action, sometimes actually diminishing the crop. In any case, they rarely prove economical; the cost of the manure usually exceeding the value of the extra produce.

GRASS LAND.

The effect of any manuring on grass land is particularly difficult to estimate, for mere bulk of produce is only one of several factors—such as the botanical composition, the feeding value, and the readiness with which stock eat the grass. We will first consider the effect of sulphate of ammonia on the weight of the crop only.

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* "Ann. der Landw.," VII. and VIII. † "Bied. Centr.," 19.

Influence of Sulphate on Weight of Produce.

At Rothamsted, in the first twenty years of experiment, the following were the average weights of hay per acre per annum, produced on the plots mentioned :—

Table XXXVIII.

Unmanured	21¼ cwt.
Mineral manures	35¼ ,,
Minerals and ammonia salts	51 ,,
Minerals and nitrate of soda	57 ,,

Both the nitrogenous manures gave a very large increase when used with minerals; but nitrate of soda produced considerably more hay on the average than ammonia salts. In comparing these two manures in order to estimate their use on the farm, however, we must remember that, used over a long series of years in large quantities, ammonia salts cause a heavy loss of lime from the soil, and the land therefore becomes sour and unfavourable for plant growth, especially in the case of permanent grass. Thus at Rothamsted, after a time, the soil of plots dressed with ammonia salts became so sour that in 1881 part of each plot was dressed with chalk, to sweeten the land and replace the lime which had been lost. The effect of this was to increase the yield of these plots, and check the deterioration which had occurred up to that time. In ordinary farm practice, this souring of the soil would not occur to the same extent; and the two manures, sulphate and nitrate, would act under more equal conditions. We see this in the average results for the first seven years of experiment on the plots at Rothamsted mentioned above. The average produce of hay per acre per annum for that period was—

Table XXXIX.

Unmanured	25½ cwt.
Mineral manures	35 ,,
Minerals and ammonia salts	56¾ ,,
Minerals and nitrate of soda (five years only) . .	51½ ,,

At first, then, ammonia salts gave the higher produce; but owing to their continuous application, the crop became unhealthy, so that over the longer period nitrate produced the heavier average yield.

Generally, therefore, in experiments on grass land on the continuous use of manures, we find that nitrate gives the higher yield of grass or hay per acre. Thus in the experiments carried out by the Highland and Agricultural Society, at Pumpherston, nitrate with superphosphate and potash salts gave an average of 35·4 cwt. of hay, against 32·8 cwt. yielded by sulphate of ammonia with the same mineral manures. In the grass experiments at the Roya Agricul-

tural College, Cirencester, a full manuring containing nitrate produced more hay than one containing sulphate of ammonia, though the average of all the plots dressed with sulphate was higher than that of the plots receiving nitrate. It may be noticed, in passing, that in the Cirencester experiments potash manures seemed to have an unfavourable effect on the action of sulphate of ammonia, but to have assisted that of nitrate of soda.

Passing on to experiments on land in ordinary farming condition, the evidence is somewhat conflicting. In some experiments carried out in 1894, under the direction of the Durham College of Science, on six farms in Durham and Northumberland, the following weights of hay were obtained :—

TABLE XL.

No manure	37¾ cwt.
Superphosphate and kainite	43¼ ,,
Superphosphate, kainite, and sulphate of ammonia .	45¾ ,,
Superphosphate, kainite, and nitrate of soda . . .	46¾ ,,

Nitrogenous manures here gave a very small increase when added to minerals; nitrate being slightly better in this respect than sulphate of ammonia.

Similar results were obtained on nine farms in Cumberland, in 1895 and 1896, when the following average weights per acre per annum were obtained :—

TABLE XLI.

No manure	17⅞ cwt.
Basic slag, kainite, and sulphate of ammonia . . .	25 ,,
Basic slag, kainite, and nitrate of soda	25⅜ ,,

On the other hand, in an experiment carried out on twelve farms in Yorkshire, under the direction of the Yorkshire College, the following average weights of hay per acre were obtained from the application of the manures mentioned :—

TABLE XLII.

Manures.	Alone.	With Sulphate of Ammonia.	With Nitrate of Soda.	With 10 tons Farmyard Manure.
	Cwt.	Cwt.	Cwt.	Cwt.
Unmanured	26	31½	27¼	30
Superphosphate, 3 cwt. .	23¾	33	31¼	30½
Bone dust, 3 cwt. . . .	23¼	33¼	30½	32
Kainite, 3 cwt.	25¾	33¼	31½	33¼
Superphosphate, 3 cwt.; kainite, 3 cwt.	27¾	36¾	34¼	36
Dissolved bones, 3 cwt. .	25½	37	33¾	37¾
Average	25¼	34	31½	33¼

Equal weights of sulphate of ammonia and nitrate of soda were used—1 cwt. in each case—so that more nitrogen was applied to the sulphate plots. The season was, on the whole, unfavourable to the action of artificial manures; and it is a curious result that of the plots dressed with non-nitrogenous manures, all but one yielded less hay than the unmanured land, the exception being the plot receiving superphosphate and kainite. Nitrogenous manures in every case gave a marked increase; and in each of the six sets of comparable plots sulphate of ammonia produced a heavier crop than nitrate of soda—the average produce being 2½ cwt. of hay in favour of sulphate.

The figures relating to farmyard manure are given for comparison. It is remarkable that in a season apparently more favourable for the action of farmyard manure than for that of artificials, the average produce from sulphate of ammonia should be slightly higher than that from farmyard manure; and not only on the average, but in four of the six sets of comparable plots, sulphate gave the heavier yield, and in a fifth set the two manures produced equal crops.

As a matter of course, the residue left after the crop was removed would be far greater in the case of farmyard manure; but against this must be put its high cost and expense of applying, in all probability five or six times the cost of using a hundredweight of sulphate of ammonia. In this instance, there is no question that sulphate of ammonia paid better than farmyard manure.

Comparing the farmyard manure plots with the nitrate plots, we find that in every case but one the former gave the best results; superphosphate and nitrate being the only exception.

We may therefore conclude that, though varying in its effect under different conditions, sulphate of ammonia compares favourably in its effects on grass land with any other nitrogenous manure. If used in large quantities at short intervals, it will certainly make the land sour after a time, by causing loss of lime as already explained; but it is not in this way that farmers need to use it. In practice it should rather be applied occasionally to supply nitrogen in an effective and economical form, not to displace altogether farmyard or mineral manures, which supply other essential constituents of plant food.

The Influence of Sulphate on the Botanical Composition of the Herbage.

It has been shown clearly in the Rothamsted and other experiments that continuous manurial treatment of any kind invariably has a marked influence on the botanical composition of the herbage. Thus, continuous use of nitrogenous

manures had, by the seventh year of the Rothamsted experiments, so strengthened and encouraged the growth of the grasses that the clovers and other leguminous plants had practically disappeared. At the same time, a change of character took place in the plants which were present; a large proportion of leaf, and comparatively few stems and seeds, being produced. The plants were also late in coming to maturity, apparently later with ammonia salts than on the plots manured with nitrate of soda.

The following table* shows the principal grasses found on plots variously manured in the seventh season of experiment, and the weight of each per cent. in the hay crop of that year :—

TABLE XLIII.

——	Unmanured.	Mineral Manures.		
		Alone.	With Ammonia Salts.	With Nitrate of Soda.
Downy and yellow oat grasses	11·1	16·7	18·1	4·8
Rough and smooth stemmed meadow grasses . . .	2·7	6·7	12·7	17·1
Perennial ryegrass . . .	6·6	3·0	11·9	10·0
Common bent grass . . .	7·1	2·8	11·6	1·8
Yorkshire fog	4·9	4·9	11·1	6·7
Cocksfoot	3·5	2·8	5·0	11·6
Soft brome-grass	0·1	0·6	2·2	9·4
Hard and meadow fescues .	15·0	12·8	4·3	2·6
Tall oat grass	2·0	5·3	0·1	3·1
Total graminaceous herbage	74·1	66·4	89·7	89·7
Total leguminous herbage .	6·9	24·1	0·1	0·9
Total miscellaneous herbage	19·0	9·5	10·2	9·4

The increase of the grasses and diminution of clover and other leguminous plants, by the use of nitrogenous manures is very remarkable; and almost equally so is the difference in effect of ammonia salts and nitrate of soda on individual species. Thus, ammonia salts had greater effect than nitrate of soda in encouraging the downy and yellow oat grasses, common bent grass, and to a lesser extent Yorkshire fog, and the fescues; while nitrate increased the meadow grasses, cocksfoot, and soft brome grass more than ammonia salts.

Similar results were obtained in the Highland and Agri-

* "Journal of the Royal Agricultural Society of England," Vol. XXIV.

cultural Society's experiments at Pumpherston.* A mixture of grass seeds was sown in 1887, and careful observations were made year by year as to the proportion of the different plants surviving on each of the variously manured plots. The following table shows the number per cent. of each species in the seed sown; the number of plants of each species, per cent., growing in 1893, the last year of the experiment, on three differently treated plots; and the weight per cent. of produce of each species on the same plots on the average of the three years 1891-3. The column No. 1 gives the results of the plots receiving no manure, No. 2 those of the plot manured with phosphates and potash, and No. 3 those of the plot to which sulphate of ammonia was given in addition to phosphates and potash.

TABLE XLIV.

	Number Per Cent. of Seeds Sown.	Number of Plants, Per Cent., 1893.			Weight Per Cent., Average, 1891-3.		
		1	2	3	1	2	3
Perennial ryegrass	5·3	10·5	7·8	5·6	6·0	4·2	3·0
Cocksfoot	11·0	22·8	26·6	27·8	34·0	53·0	51·0
Timothy	13·0	3·3	1·7	1·1	5·0	6·0	3·3
Dogstail	2·6	15·1	12·1	16·5	26·0	17·0	21·0
Foxtail	7·3	..	0·3	1·7	..	0·3	2·0
Meadow grasses	28·0	2·1	2·6	1·5	0·7	1·4	0·7
Fescues, meadow, and tall	6·6	6·1	4·8	3·7	11·0	6·0	3·5
Fescues, sheep's and hard	6·4	22·2	10·3	3·0	4·0	2·0	0·7
Yorkshire fog	..	15·4	25·4	31·7	8·5	10·0	12·5
Clover	19·0	2·5	6·5	3·7	0·5	1·1	0·6
Weeds	..	..	1·9	2·0	..	0·1	0·4

In no case did the species appear at the end of the experiment in the same proportions as in the seed. Speaking generally, cocksfoot, dogstail, and the weed grass, Yorkshire fog, had largely increased, and most of the other grasses and clover had diminished. But the extent of this increase and decrease is very different in the different plots. Thus, considering the weight of the produce, cocksfoot increased much more in the manured than in the unmanured plots, but dogstail was more important relatively in the latter case. Ryegrass had somewhat increased in proportion on the unmanured land, but had diminished on the other plots—chiefly on that receiving sulphate of ammonia.

Influence on Palatability and Feeding Value.

More important than the changes in the botanical composition of the herbage is the palatability of the produce for

* "Transactions of the Highland and Agricultural Society," Vol. VI., Fifth Series.

stock, and its feeding value to the animal when eaten. On these points there is little reliable information, owing to the difficulty of such inquiries. At the close of the Pumpherston experiments (some of the results of which have just been given), the whole of the area of experiment was grazed; and several times during the season the extent to which the different plots were fed down was estimated. The following were the averages of these estimates; 100 representing that the crop was fed down as close as possible, 50 that 50 per cent. had been eaten, and so on :—

Table XLV.

Unmanured	45 p.c.
Superphosphate	65 ,,
Potash salts	78 ,,
Sulphate of ammonia, phosphates, and potash	47 ,,
Nitrate of soda, phosphates, and potash	27 ,,

The stock evidently preferred the crops grown without nitrogen; but from a farmer's point of view, the small bulk usually obtained from the use of mineral manures alone makes such dressings undesirable. The difference between sulphate and nitrate is considerable, and, taken in conjunction with the yields from these plots (nitrate 35·4 cwt. of hay, sulphate 32·8 cwt.), shows a decided superiority in the effect of sulphate of ammonia.

One other experiment bearing on this point may be mentioned, though it has not been carried far enough yet to give very reliable results. On the Northumberland County Council Farm, plots of poor grass land manured in various ways were grazed in 1897 by sheep, and the increase in live weight noted on each plot. In the four months of experiment, the following live weight increase was obtained per sheep and per acre :—

Table XLVI.

Manuring in 1897.	Live Weight Increase.	
	Per Sheep.	Per Acre.
	Lbs.	Lbs.
No manure	14·0	37·3
Superphosphate, 7 cwt.	21·1	56·3
Superphosphate, 7 cwt.; sulphate of potash, 1½ cwt.	27·1	72·3
Superphosphate, 7 cwt.; sulphate of ammonia, 97 lbs.	29·6	79·0

This is an experiment which obviously needs to be repeated frequently before it would be safe to generalize

from the results obtained; but as they stand, the above figures point to a striking increase in feeding value per acre, resulting from the use of sulphate of ammonia with superphosphate. A number of manurings were tested in the same way; but this gave the highest live weight increase.

In the following year, however, when the same plots were again grazed with sheep, but no further manure was applied, sulphate of ammonia and superphosphate gave comparatively poor results. The produce was still not far short of double that of the unmanured plot; but the mineral manures—particularly basic slag—gave relatively much better results. This is very much what we should expect from the consideration of the principles controlling the action of sulphate of ammonia. A residue is left beyond the first year after application; but a considerable loss of nitrogen takes place by drainage, especially during the winter. This loss is less in the case of grass land than from arable; but still sulphate of ammonia cannot be expected to produce relatively good results in the second season after application, compared with mineral manures, the valuable constituents of which are held safely by the soil. That the time elapsed since the sulphate of ammonia was applied had some influence in causing the inferior returns in the second year of experiment, seems more probable from the fact that in the autumn and early winter of 1897-8, when all the plots were grazed by store cattle, the plot manured with sulphate of ammonia and superphosphate carried the largest amount of stock; being equalled only by that dressed with half a ton of basic slag. So that up till then at least, it was still doing well.

It will be noticed that, in these Northumberland experiments, no other purely nitrogenous manures were employed; so that no further light is thrown on the effect of sulphate of ammonia compared with nitrate of soda.

The available experiments, therefore, all seem to show that sulphate of ammonia has a good effect on the feeding value of the crop, besides giving a large increase in its bulk. Used occasionally, and in moderate quantity—say, from 1 to 1½ cwt. per acre—the necessary minerals being also present in the soil or manure, sulphate of ammonia will give a better result on the average than any other purely nitrogenous manure, if both the quantity and the quality of the produce be taken into account.

We have now considered the general principles involved in the use and action of sulphate of ammonia, and its effect on the chief farm crops individually, as shown by experiment. The conclusion arrived at is that, when used judiciously, sulphate of ammonia is a most valuable nitrogenous manure. But it must be repeated that it supplies only

nitrogen to crops, and therefore cannot be used with good effect unless phosphates, and usually potash also, are added to the soil. These mineral manures may often be applied to one crop in the rotation, and sulphate of ammonia to another; and the minerals may be given as artificials or as farmyard manure, or partly in one form and partly in the other. But at some time in a series of years, and in one or other form, minerals must be given, or the use of nitrogenous manures cannot prove satisfactory.

SUMMARY.

1.—Sulphate of ammonia is a nitrogenous manure, and must be considered as a source of nitrogen only.

2.—Nine other elements besides nitrogen are essential for plant growth, of which phosphates and potash, as well as nitrogen, must usually be supplied in the manure.

3.—Combined nitrogen only can be used by plants.

4.—Combined nitrogen in Nature is supplied to the soil only in small quantities, and is subject to constant loss. The addition of nitrogenous manures is therefore needed.

5.—Nitrogenous manures cause larger leaf growth, increased chlorophyll formation, slower maturity, and increased crops generally.

6.—Organic nitrogen is of no direct use to the plant. Nitric and ammoniacal nitrogen are both directly useful, though the latter almost always undergoes nitrification before use.

7.—Ammoniacal manures generally fail to give their maximum result unless potash is liberally supplied by soil or manure.

8.—Sulphate of ammonia reacts in the soil with carbonate of lime, and carbonate of ammonia is formed, which can then be fixed by the clay and humus of the soil.

9.—Nitrogen may be lost by the volatilization of carbonate of ammonia, when sulphate of ammonia has been applied to very calcareous soils; but this is rarely important.

10.—Nitrification of ammonia compounds, especially sulphate of ammonia, may be very rapid when everything is favourable. It is more rapid than the nitrification of organic nitrogenous matter.

11.—After nitrification, the nitrogen is subject to loss by drainage.

12.—Sulphate of ammonia is most effective in wet climates and seasons.

13.—A small dressing of sulphate of ammonia may be applied to autumn sown crops in autumn, but most of it should be put on in spring. For all other crops, it should be used at, or a little before, the time of sowing the seed. If applied late in the growth of the crop, sulphate of ammonia may cause too great rankness.

14.—Sulphate of ammonia may be applied longer before sowing on heavy land than on light. It is less suitable for very calcareous soils than for either sandy or clay soils, and still less so for soils deficient in lime.

15.—Sulphate of ammonia may leave a valuable residue in the soil after the removal of the crop to which it is applied.

16.—Too large a dressing of sulphate of ammonia causes injury from over-rankness of growth and late maturity, especially if mineral plant food be deficient in the soil.

17.—Sulphate of ammonia should be mixed with dry ashes, sand, &c., for convenience of sowing, or with other manures, except those which contain lime or carbonate of lime, or which are damp.

18.—Commercial sulphate of ammonia should be of 95 to 97 per cent. purity, containing about 24 to 25 per cent. of ammonia. The chief impurities, apart from sandy matter, are common salt, sulphate of soda, sulphate of iron, arsenic, sulphuric acid, and thiocyanate of ammonia, of which the last three are most injurious.

19.—On wheat, sulphate of ammonia increases the quantity of the produce and improves its quality. About 1 cwt. per acre should be given.

20.—On barley, sulphate of ammonia gives large increase, and on the average produces a better malting sample than other nitrogenous manures. Average dressing, $\frac{3}{4}$ cwt. to 1 cwt. per acre.

21.—On oats, sulphate of ammonia usually yields a larger increase of grain than nitrate of soda, and of straw also if potash be plentifully supplied. Average dressing, about 1 cwt. per acre.

22.—On mangels, when farmyard manure is used, sulphate of ammonia is probably superior to nitrate of soda in produce per acre of food for stock, and often in weight of crop. Without farmyard manure, it has rather less effect. Average dressing, 1 to 2 cwt. per acre.

23.—On turnips, sulphate of ammonia compares favourably with nitrate, giving as large or larger crops, which apparently keep better. Average dressing, about 1 cwt. per acre.

24.—On potatoes, sulphate of ammonia gives very large increase—almost always larger than that from nitrate of soda. Sulphate is also less favourable to the development of disease. Average dressing, 1 to 2 cwt. per acre.

25.—On beans, sulphate of ammonia does not give any profitable result.

26.—On clover, sulphate of ammonia is as effective as other nitrogenous manures, but is rarely profitable.

27.—On grass land, sulphate of ammonia produces a yield in weight about equal to, or slightly less than, nitrate of soda. It specially encourages the grasses at the expense of the clovers. The produce seems to be more palatable to stock than that of nitrate of soda, and to have a high feeding value. Average dressing, 1 to $1\frac{1}{2}$ cwt. per acre.

NOTE.—In the above summary, all comparisons between sulphate of ammonia and nitrate of soda are between equal quantities of nitrogen in the two forms. This is equivalent to comparing the effect of a little over $\frac{3}{4}$ cwt. of sulphate with that of 1 cwt. of nitrate.